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I. INTRODUCTION

Environmental concerns and technological changes are closely interrelated factors in agricultural production. Technical innovations in the form of improved farming practices and new and more intensive applications of chemical inputs have resulted in an upward trend in grain yields. However, the increased usage of chemical inputs such as fertilizers, insecticides, and herbicides may also be significant sources of pollution. Other environmental concerns such as soil loss and the disposal of livestock wastes affect agricultural production capabilities and may degrade soil and water quality. In addition, weather variability causes significant year-to-year fluctuations in grain yields around trend levels and is one of the most important sources of uncertainty in future grain supplies.

Most environmental factors other than weather can be controlled within limits by the application of appropriate management and farming techniques. Weather, on the other hand, is for the most part uncontrollable. Other than in limited areas of irrigation, a farmer is primarily dependent upon nature to determine the growing conditions his crop will experience. General weather conditions and the degree of variability in weather from year-to-year are quite different from region to region within the United States. Thus, environmental policies that change regional production patterns also change the expected variability in agricultural production due to weather conditions.

The world food situation has become highly volatile in recent years as the rapid increase in world population has increased demand while concurrently adverse weather conditions in many parts of the world have reduced supplies and depleted most of the world's grain reserves. In addition, increasing concern over the quality of the environment in the United States threatens to restrict the future use of some chemical inputs and production practices, putting added pressure on world grain supplies. Under the present circumstances, U.S. agriculture plays a dominant role in the grain market. More than 20 percent of the world grain output and more than 40 percent of the total world grain trade is produced in the United States. Thus, developments in energy, environmental quality, and world grain stocks have primary impacts on U.S. agriculture.

II. OBJECTIVES

Given the complex interrelationships between the environment, technology, and U.S. agriculture, this study evaluates the relationships between various agricultural environmental policies and the corresponding weather-induced variation in grain production. Alternatives that will be analyzed include a restriction on nitrogen fertilizer usage, a maximum allowable per acre soil loss, a livestock waste runoff control policy, a limited restriction on organochlorine insecticides, and a measure of the effect of all four environmental policies on the overall U.S. production capacity. Each policy is analyzed to determine if the resultant changes in regional production patterns cause an increase or decrease in the expected variation in U.S. grain production.

A second objective is to determine the optimum size of a grain reserve needed to offset fluctuations in grain production when the reserve is designed to meet various proportions of the domestic and foreign shortfalls in grain production. Alternatives considered are: (1) reserve to meet 90 percent of U.S. shortfalls and 60 percent of foreign, (2) reserve to meet 90 percent of U.S. shortfalls and 75 percent of foreign, and (3) reserve to meet 90 percent of U.S. shortfalls and 60 percent of foreign shortfalls simultaneously. This study considers the effects of weather-induced shortfalls when the worst weather in terms of grain production expected in 10-, 20-, and 40-year periods actually occurs in 1985. Food grains (including wheat, rice, rye, and soybeans) and feed grains (including corn, barley, oats, and sorghum) are analyzed separately.

III. METHODS USED AND MODEL DEVELOPMENT

A nonlinear regression analysis is used for the statistical estimation of the weather effect in grain yields [7, 12, 14, 15, 19, 20]. The weather effect is defined as the degree of variability in grain yields attributable to weather. The weather effect under an unrestricted situation is compared to the weather effect when an environmental restriction is imposed on agriculture. Data for the restricted cases were obtained from environmental policy models developed by the Center for Agricultural and Rural Development [27].

Regions Used in the Analysis

Several regional delineations are used in this study. Grain production is determined by the 105 producing areas (Figure 1). These producing areas

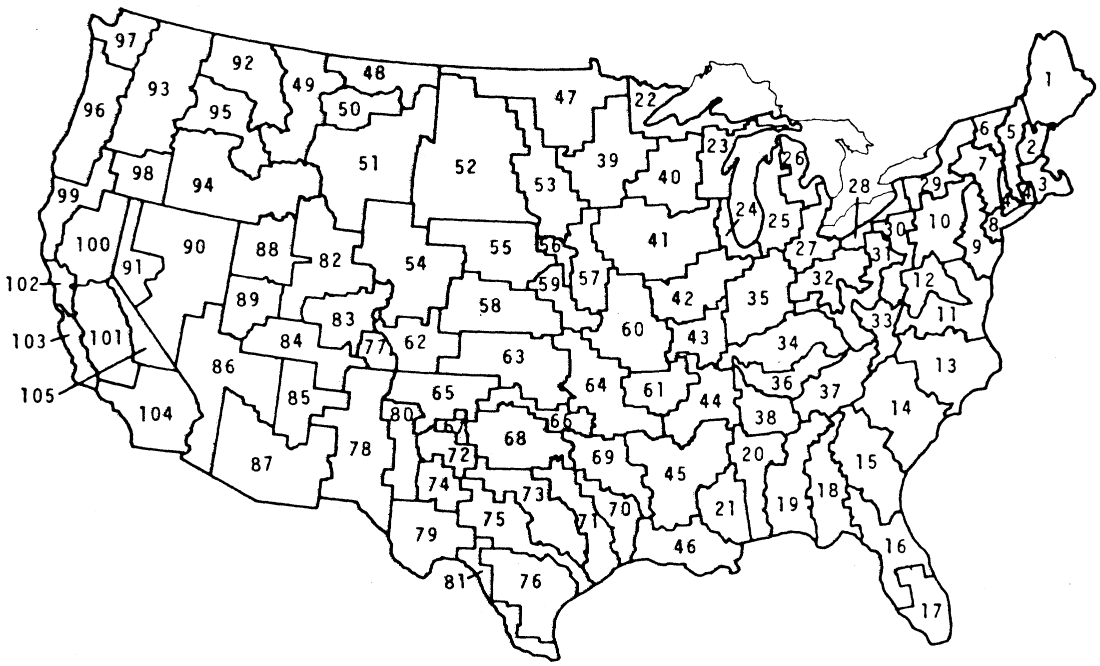

Figure 1. The 105 producing areas

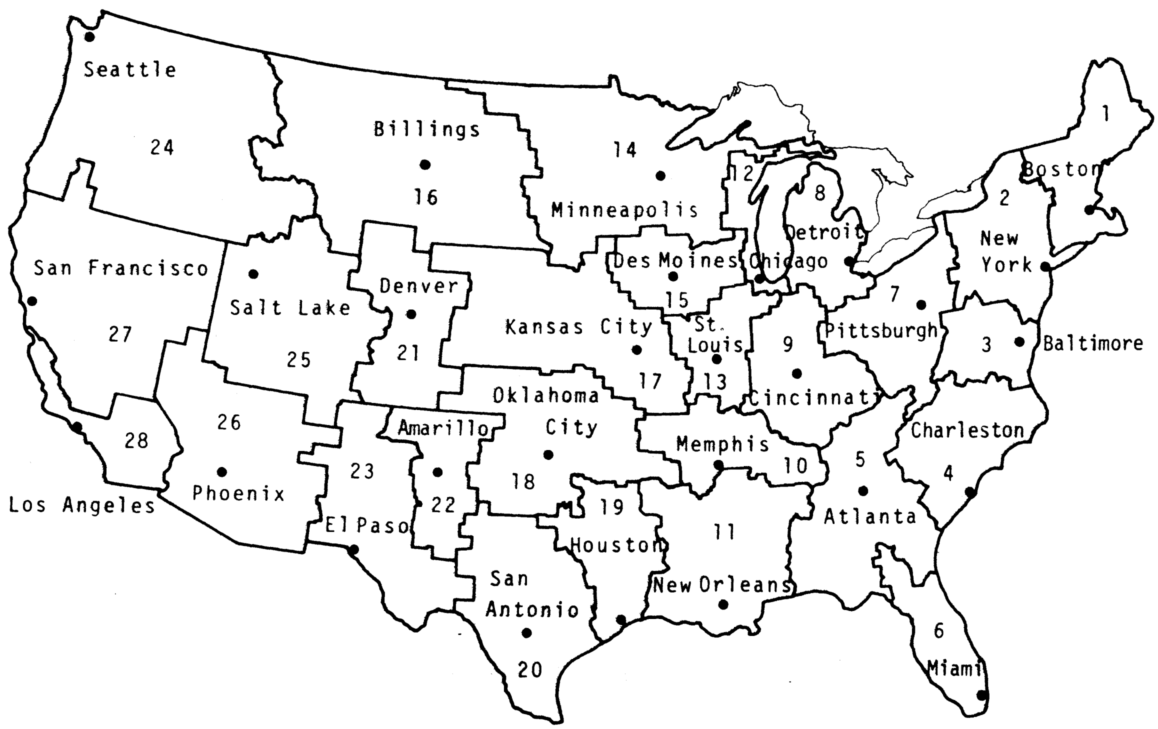

Figure 2. The 28 market regions with central cities indicated

are used to determine the regional shifts in production that occur as a result of environmental policy restrictions. Regional demands for grain are estimated by the 28 market regions (Figure 2). Frequently, the 48 contiguous states are used to present the results of the study. Documentation of the regional delineations is included in [9].

To collect world grain production data for estimating world grain shortfalls, the world is divided into 11 major grain producing and consuming areas as follows: United States, Canada, Argentina, Brazil, Western Europe, USSR, India, Africa, Oceania, and Asia. Grain yield and production data over the 20-year period, 1952 to 1971, are used to estimated weather effects in these 11 regions.

Statistical Estimation of Weather Effects

Grain yields depend upon technology, weather conditions, input prices, lagged grain prices, and acreage engaged in production. A quantitative measurement of weather conditions throughout the year is complicated and does not represent the real impact of weather on grain production because of seasonal weather variability. Consequently, weather's effect on grain yields is defined as the residual of a regression equation where yields are expressed as a function of the prices of all chemical inputs, lagged grain prices, acreage, and technology. However, all independent variables except a time trend, representing technology, are statistically insignificant in estimating grain yields. Thus, grain yields are expressed simply as a function of a time trend.

Technical innovations in farming practices and new and more intensive use of chemical inputs and hybrid seeds are primarily responsible for the upward trend in yields. Deviations from the trend level represent the effects of all other factors including weather, prices of all chemical inputs, and grain prices. However, the deviations from the trend level are assumed to be primarily the result of weather variations because of the insignificance of the price variables in the yield equations. Therefore, the technology and weather effects are calculated using the following grafted polynomials [6].

$$Y_{it}^{j} = \alpha_{oi}^{j} + \beta_{oi}^{j} t + U_{it}^{j} \qquad t \leq t_{i}^{*j} \qquad (1)$$

$$Y_{it}^{j} = \alpha_{1i}^{j} + \beta_{1i}^{j} t + V_{it}^{j} \qquad t > t_{i}^{*j} \qquad (2)$$

where

Y_{it}^{j} = yield of crop i at time t in region j

t_{i}^{*j} = the transition year (between 1954 and 1958) for crop i and region j

t = time variable

U_{it}^{j}, V_{it}^{j} = deviations from the trend for crop i at time t in region j caused primarily by weather variations.

At time t_{i}^{*j} equations (1) and (2) are continuous allowing us to write:

$$\partial_{0i}^{j} + \beta_{0i}^{j} t_{i}^{*j} = \partial_{1i}^{j} + \beta_{1i}^{j}\ t_{i}^{*j} \qquad (3)$$

Solving equation (3) for α^j_{1i} gives

$$\alpha^j_{1i} = \alpha^j_{0i} + (\beta^j_{oi} - \beta^j_{1i})\ t^{*j}_i \tag{4}$$

Substituting equation (4) into equation (2) and adding and substracting β^j_{0it} gives:

$$Y^j_{it} = \alpha^j_{0i} + \beta^j_{0i}t + Z^j_{it}\ [\beta^j_{1i} - \beta^j_{0i}] + e^j_{it} \tag{5}$$

where

$$Z^j_{it} = \begin{cases} 0, & t \leq t^{*j}_i \\ t - t^{*j}_i, & t > t^{*j}_i \end{cases}$$

and e^j_{it} is the deviation from the trend for crop i in region j caused primarily by weather variations.

Actual grain yields from the period 1921 through 1974 were used in estimating the regression equations [21, 22]. A major increase in grain yield trends occurred in the mid-1950s. This increase in yield trends can be attributed to rapid adoption of technological improvements such as hybrid varieties, increased usage of chemical inputs, especially nitrogen fertilizer, and usage of larger machinery complements. The grafted polynomial approach allows us to account for this shift. Table 1 gives the empirical results for the various grains for the United States as a whole.

Table 1. Estimated regression coefficients of grafted polynomials of grain yields in the United States

Grain	Regression Coefficients			R^2
	Constant	t	z	
Wheat	6.73	0.237 (8.18)[a]	0.452 (5.63)	0.890
Corn	2.79	0.750 (9.44)	1.86 (8.42)	0.931
Oats	18.9	0.325 (6.01)	0.571 (3.82)	0.804
Barley	13.7	0.268 (6.59)	0.641 (5.68)	0.864
Sorghum	0.983	0.436 (5.59)	1.51 (6.95)	0.869
Soybeans	5.32	0.301 (22.62)		0.906

[a]Values in parentheses are t values associated with the independent variables in the regression equations.

The average effect of weather over time[1] on the yield of crop i in region j is given by

$$W_i^j = \frac{\sum_{t=1}^{n} \left| e_{it}^j \right|}{\sum_{t=1}^{n} Y_{it}^j} \times 100 \qquad (6)$$

where

Y_{it}^j = actual yield of crop i in time t in region j;

e_{it}^j = deviation from the trend for crop i in time t in region j

A weather index is then calculated by dividing the weather effect for each grain in each state by a weighted average weather effect over regions.

$$W_i = \frac{1}{J}\sum_{j=1}^{J} W_i^j \qquad (7)$$

$$WI_i^j = \frac{W_i^j}{W_i} \times 100 \qquad (8)$$

---

[1]An alternative definition of average effect of weather is

$$W_i^j = \sum_{t=1}^{n} \frac{\left| e_{it}^j \right|}{\hat{Y}_{it}^j} \times 100$$

This alternative definition relates each deviation to the predicted yield at a particular t. The rationale for this definition is based on the result that if the trend yield grows rapidly through time the expected residual could also grow rapidly even though the percentage deviation would be the same. However, in sample cases the authors found the difference in the results between the two definitions to be less than five percent.

where

WI_i^j = weather index for crop i in region j

W_i = weighted average weather effect over regions for crop i

W_i^j = the average weather effect for crop i in region j

A weather index value of 100 indicates that the variation in yields due to weather in a state is the same as the average national variation. A weather index value greater than 100 indicates that the variations in yields due to weather is greater than the average variation and a weather index less than 100 indicates that the variation is less than the average variation. The state weather index values aggregated over feed, food, and all grains are listed in Table 2.

Joint Effects of Weather and Environmental Policies

Implementation of an environmental policy may change the regional distribution of grain production and the associated impact of weather on grain production. The impact of an environment policy on the expected variability in production due to weather is calculated as follows:

$$WI_i^E = \frac{\dfrac{\sum_{j=1}^{48} WI_i^j \cdot P_i^{jE}}{\sum_{j=1}^{48} P_i^{jE}}}{\dfrac{\sum_{j=1}^{48} WI_i^j \cdot P_i^{jB}}{\sum_{j=1}^{48} P_i^{jB}}} \times 100$$

Table 2. Estimated weather index by states

State	Feed grains	Food grains	All grains
Maine	36	--	35
New Hampshire	--	--	--
Vermont	53	--	51
Massachusetts	--	--	--
Rhode Island	--	--	--
Connecticut	--	--	--
New York	84	51	75
New Jersey	104	88	96
Pennsylvania	82	61	76
Delaware	135	131	133
Maryland	87	96	89
Michigan	79	64	73
Wisconsin	70	85	68
Minnesota	90	76	84
Ohio	72	71	72
Indiana	78	64	71
Illinois	88	64	77
Iowa	83	67	77
Missouri	109	92	100
North Dakota	119	129	126
South Dakota	148	160	149
Nebraska	139	133	135
Kansas	139	120	128
Virginia	100	85	93
West Virginia	75	62	70
North Carolina	99	84	92
Kentucky	92	66	81
Tennessee	82	91	90

Table 2 (continued)

State	Feed grains	Food grains	All grains
South Carolina	95	113	110
Georgia	125	102	117
Florida	120	114	116
Alabama	116	123	121
Mississippi	108	105	110
Arkansas	98	106	111
Louisiana	103	78	83
Oklahoma	122	134	135
Texas	101	146	113
Montana	101	100	102
Idaho	58	55	57
Wyoming	81	128	107
Colorado	95	144	130
New Mexico	151	167	155
Arizona	63	67	62
Utah	54	70	65
Nevada	57	60	57
Washington	70	61	64
Oregon	72	71	72
California	71	74	70
U.S. Average	100	100	100

[a]Blanks indicate that production data were insufficient for regression analysis.

where

WI_i^E = relative change in weather variation under the Eth environmental policy in the production of the ith grain

WI_i^j = weather index in the jth state in the production of the ith grain

P_i^{jE} = quantity of the ith grain produced in the jth state under the Eth environmental policy

P_i^{jB} = quantity of the ith grain produced in the jth state without any environmental constraints.

A value of 100 indicates that implementation of the environmental policy does not affect the expected weather variability in grain yields. A value greater than 100 indicates an increase in the expected variability in yields due to weather and a value less than 100 a decrease in the expected variability due to weather.

IV. INFLUENCES OF WEATHER IN GRAIN PRODUCTION

Weather causes much of the year-to-year fluctuations in grain production. The fluctuations are of concern since they generate disequilibrium in the grain market. Since the demand for grains is relatively price inelastic, small changes in quantities supplied are multiplied into relatively large price changes.

A grain reserve is one technique for smoothing out supply variations. Figure 3 illustrates the relationships between alternative reserve policies, the associated costs of maintaining the reserves, and the impact of reserves on grain price variability. The quantities in Figure 3 are:

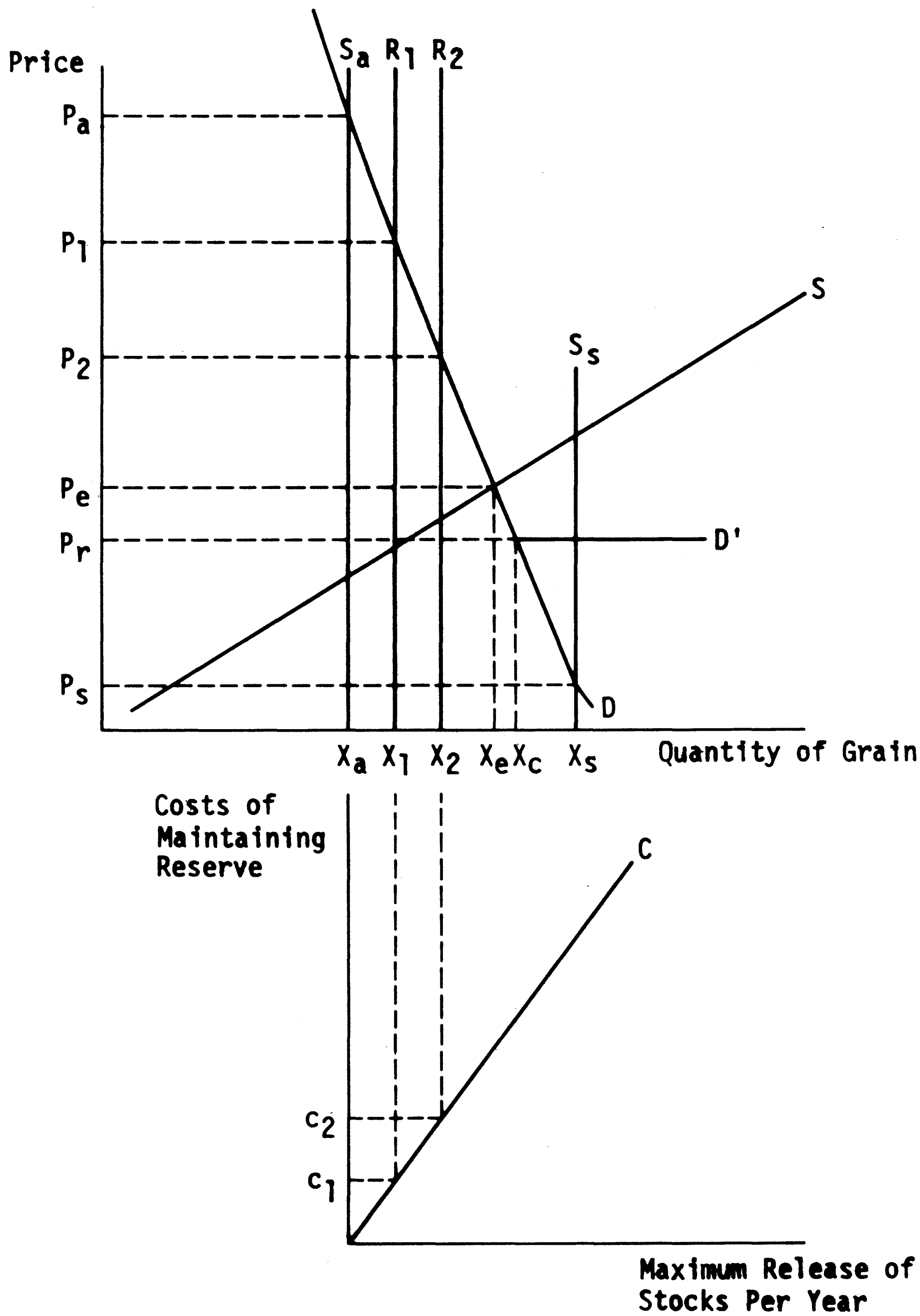

Figure 3. Relationships between alternative reserve policies, costs of maintaining the reserve, and grain price variability

S = long run market supply function.

D = market demand function.

S_a = actual supply in year of shortfall.

S_s = actual supply in year of surplus.

D' = the effective demand as a result of the stock accumulation price of P_r.

R_1, R_2 = two alternative reserve policies.

C = function relating costs of maintaining reserves to the maximum yearly release.

c_1 = cost of maintaining a reserve with maximum release per year of x_1-x_a.

c_2 = cost of maintaining a reserve with maximum release per year of $x_2 - x_a$.

x_a = actual supply in a year of shortfall.

x_1-x_a = maximum stocks released per year under reserve policy R_1.

x_2-x_a = maximum stocks released per year under reserve policy R_2.

X_e = equilibrium quantity of grain.

X_s = actual supply in a year of surplus.

x_s-x_c = government accumulation of stocks in the year of surplus.

P_s = market determined price in year of surplus.

P_r = reserve accumulation price.

P_e = market equilibrium price.

P_2 = price obtained in year of shortfalls under reserve policy R_2.

P_1 = price obtained in year of shortfalls under reserve policy R_1.

P_a = market price in year of shortfalls with no reserve policies.

The larger the reserve maintained the greater is the reduction in price variability. With no reserves the market price would vary from P_a in the year of shortfalls to P_s in the year of surplus production. Under a reserve policy with an accumulation price of P_r, the price is effectively constrained between P_r and a maximum of P_1 or P_2 depending upon the size of the reserve maintained. Since the demand for agricultural products is price inelastic, moderate reserve quantities provide a rather large reduction in price variability.

Although larger reserves provide a greater reduction in price variability, they also cost more to maintain. In Figure 3, c_1 and c_2 represent the total costs of maintaining reserves with a maximum release per year of x_1-x_a and x_2-x_a respectively.

A simulation model is used to determine the optimal levels of grain reserves needed to offset domestic and world shortfalls in grain production. The simulation model stabilizes grain supplies in both the United States and the rest of the world under the assumption that the supply of grain in any given year is completely inelastic. The degree of supply stabilization is indicated by the government's policy goals, and the minimum level of U.S. grain stocks satisfying these goals is determined. Storage and handling costs of 22 cents per bushel or $4.91 per ton per year [13] were assigned on the basis of the total contingency stocks carried from year to year. We assume that up to one-half of the available reserves can be released during any one year of shortfalls.

Weather, Technology and Grain Production

Weather and technology effect

The technology effect is defined as the linear trend in grain yields; the deviations from this trend are assumed to be the effect of weather. Table 3 lists the weather and technology effects for several grains in the United States. For example, during the period 1921-1974, approximately 87 percent of the variations in wheat yields can be attributed to changes in technology and 13 percent of the variation attributed to weather fluctuations. This compares to an average over all grains of 89 percent attributed to changes in technology and the remaining 11 percent as a result of weather variations. The individual weather effects differ among grains as the location of production of these grains differ. Much of the U.S. wheat crop is produced in the Great Plains where weather fluctuations are more severe than the U.S. average; thus wheat yields are quite variable. On the other hand, corn yields are relatively less variable since the majority of corn production is located in states where weather variations are less severe than average U.S. weather variations.

Table 3. Estimated percentages of grain yield variations attributed to changes in technology and weather fluctuations, 1921-1974.

	Technology	Weather	Total
Wheat	87.15	12.85	100
Corn	90.45	9.55	100
Oats	88.85	11.15	100
Barley	90.20	9.80	100
Sorghum	88.03	11.97	100
Soybeans	90.74	9.26	100
Average	89.31	10.69	100

Regional patterns of weather variability

Figure 4 illustrates the relative significance weather plays in grain production in each state. Weather has a greater impact on yields than the national average in areas shaded by solid lines; in areas shaded by broken lines the impact of weather on yields is less than the national average. The Great Plains, Southern Plains, Delta States and Southeast areas are characterized by relatively unstable weather. The Northeast and Cornbelt areas generally have relatively stable growing seasons, temperatures, and precipitation from year-to-year. In these areas weather has less impact on grain yields. Similarly, yields are relatively stable in the West Coast States and the states of Idaho, Utah, Arizona, and Nevada as a result of the influence of the Pacific Ocean and extensive irrigation.

The distribution of weather effects is very similar in feed and food grain production (Figures 5 and 6). However, food grain yields tend to be more variable than feed grain yields since wheat production, the major food grain, is concentrated in areas with high weather variability.

Probability distribution of weather effects

A frequency distribution of weather deviationsin the United States was constructed by simulating the regression equations in section III over the period 1921-1974. The differences between the actual and the predicted yields over the period were used in deriving Figure 7. The horizontal axis in Figure 7 represents actual yields as a percentage of the predicted trend yield. A value of 1.0 indicates that the actual yield was equal to

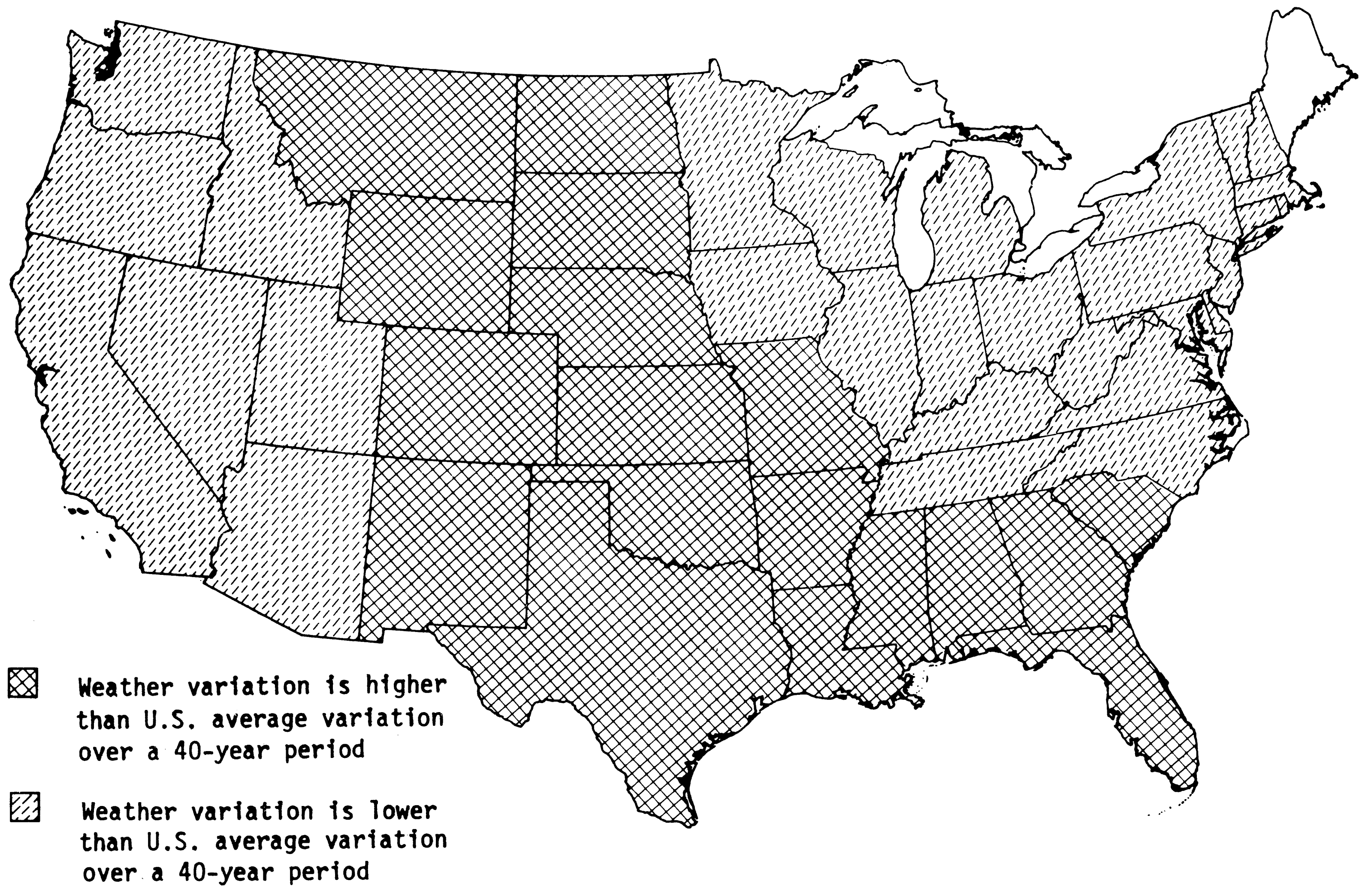

Figure 4. Regional pattern of weather effects in grain production based on the period 1921-1974

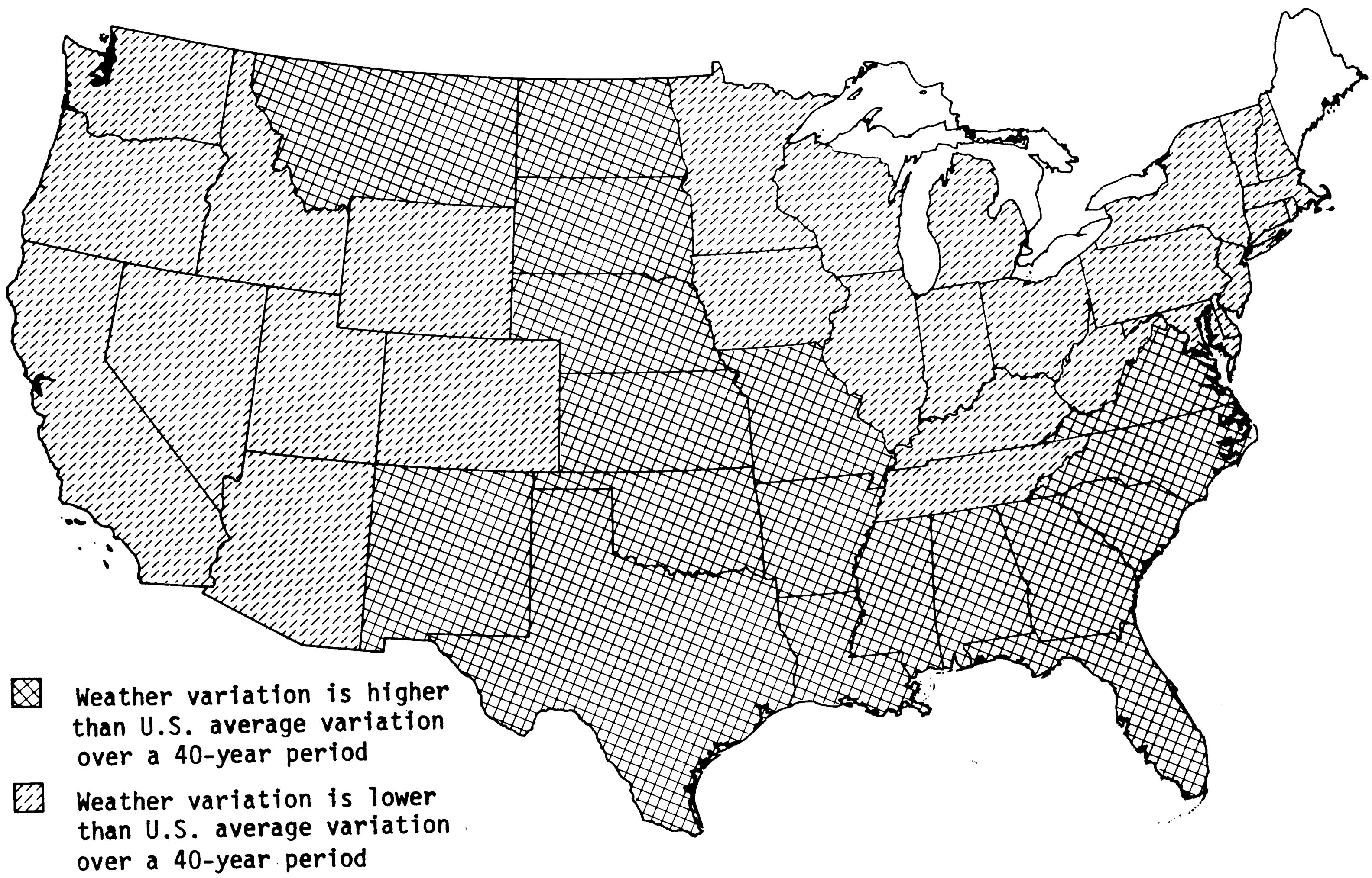

Figure 5. Regional pattern of weather effects in feed grain production (corn, oats, barley, and grain sorghum) based on the period 1921-1974

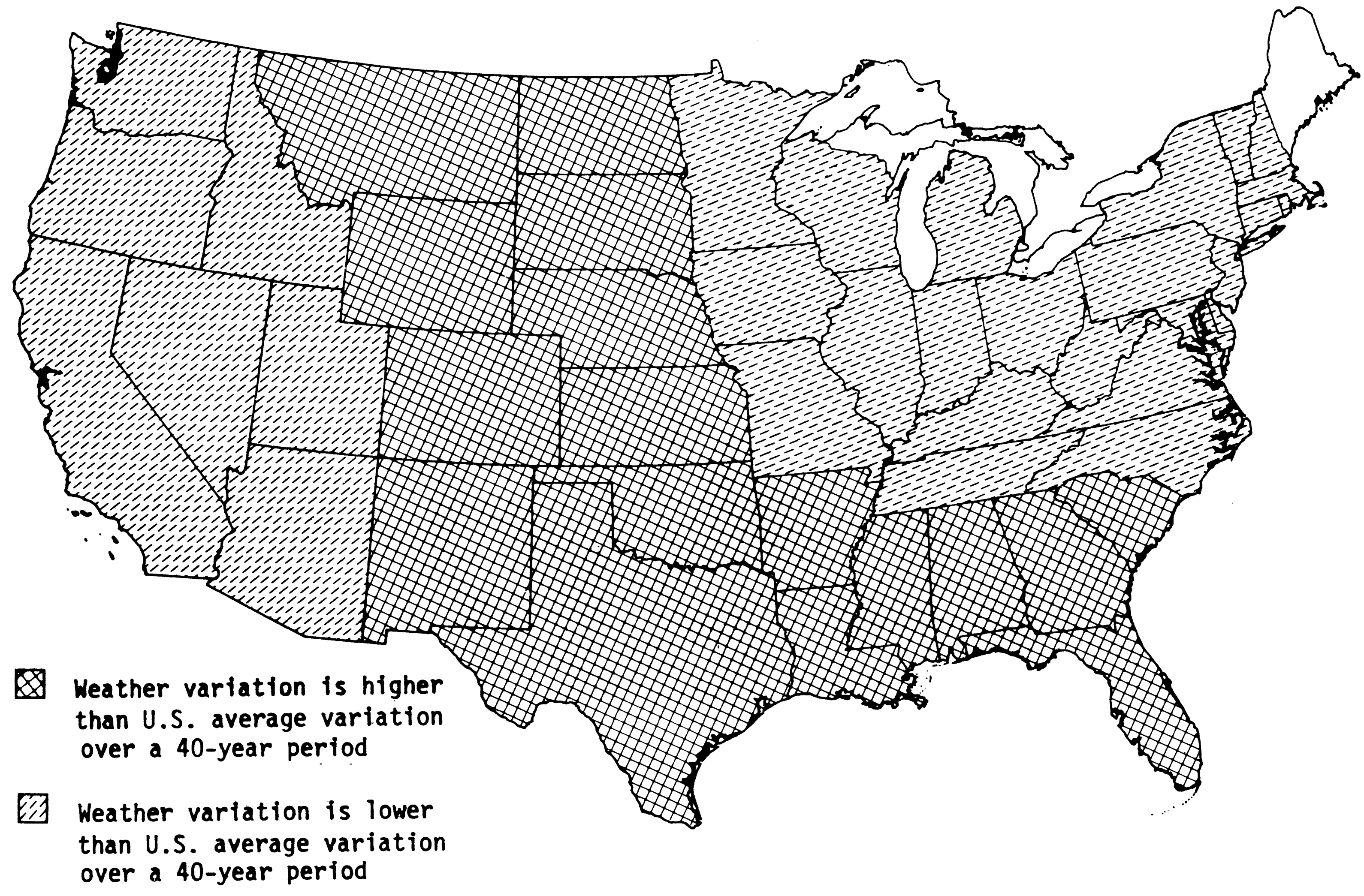

Figure 6. Regional pattern of weather effects in food grain production (soybeans and wheat) based on the period 1921-1974

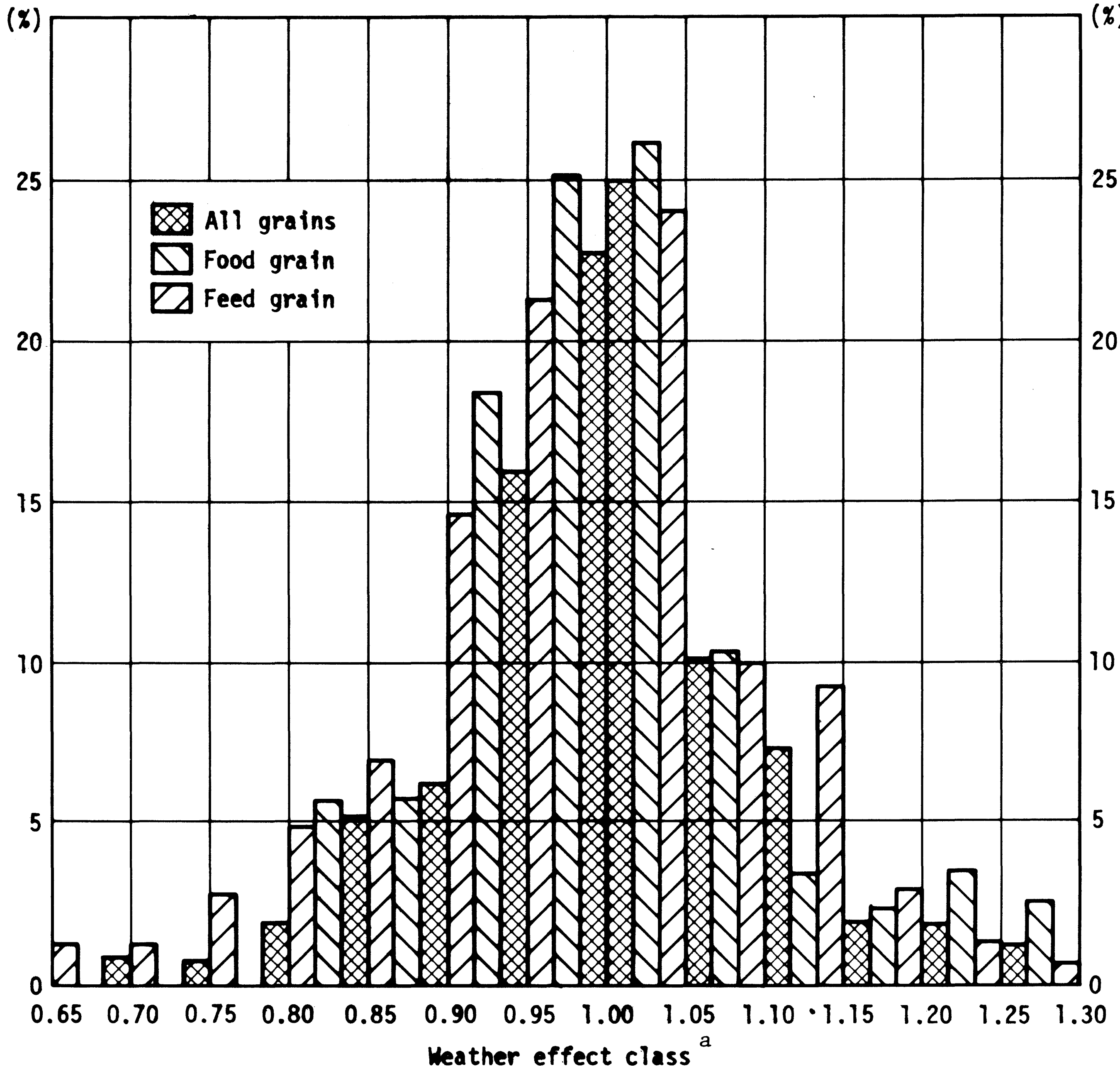

Figure 7. Frequency distribution of weather effects on U.S. grain production for the period 1921-1974

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[a]The weather effect class indicates the relationship between the observed yields and the estimated trend yields.

the predicted yield. The vertical axis indicates the frequency that actual yields relative to the predicted yields fell in each category over the period 1921-74. The distributions closely approximate bell-shaped curves characteristic of normal distributions.

Table 4 is derived from the distributions illustrated in Figure 7 in the following manner. The vertical axis in Figure 7 indicates the relative frequency of occurrence. Therefore, a 10 percent relative frequency indicates a result expected to occur once out of ten chances. The values in Table 4 are derived by finding the intersection of the 10, 5, and 2.5 (i.e., one chance in 10, one chance in 20, and one chance in 40) percentage lines with the appropriate distribution and then reading off the corresponding value on the horizontal axis. The exact values in Table 4 were obtained by a computer program rather than by visual inspection.

Table 4 indicates that the maximum expected shortfall in one year out of 10 would be 10.5 percent of all grain production. Similarly, the maximum expected shortfall in one year out of 20 is a 17.5 percent and the maximum expected shortfall in one year out of 40 is 21.5 percent of all grain production.

Table 4. Estimated reduction in U.S. grain production assuming that the worst weather expected in 10-, 20-, and 40-year periods actually occurred in a particular year (percentage of total grain production.)

	All Grains	Feed Grains[a]	Food Grains[b]
10-year	10.52	10.28	10.78
20-year	17.50	16.62	17.65
40-year	21.53	23.68	18.20

[a]Includes corn, oats, barley and grain sorghum.

[b]Includes wheat and soybeans.

V. INTERACTION BETWEEN ENVIRONMENTAL POLICIES, EXPORT LEVELS, AND WEATHER VARIABILITY

Significant interrelationships exist between environmental restrictions, export capacity, and weather-induced variability in grain production. Alternative environmental and export policies result in varying regional production patterns. By incorporating the changes in regional production with the regional weather indexes detailed in section IV, the impacts of the environmental or export alternatives can be quantified. In this section the interactions in production, utilization, and weather variability are explored for a series of environmental and export alternatives. The policy alternatives and results are detailed in [27].

Model Used to Determine Regional Production Patterns

A national interregional linear programming model similar to the one documented in [9] is used to determine the regional production patterns under the various policy alternatives. Regional delineations include 105 producing areas, 28 consuming regions, and 12 major zones. Land resources are separated into 5 soil classes based on productivity characteristics. In addition to the crop sector, the model includes endogenous livestock and transportation sectors. Major constraints include the availability of land resources by the five different soil classes, water resources in the seventeen western states, and the regional demands including exports for the major crop and livestock commodities. The model minimizes the total cost of producing and transporting the commodities to meet the regional demands, given the available land and water resources and subject to the restrictions imposed by the particular environmental policy.

Environmental and Export Alternatives Analyzed

Regional production patterns were determined for the following alternatives: 1) a maximum per acre soil loss equal to the soil tolerance level[2], 2) livestock feedlot runoff controls similar to United States

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[2]The soil loss tolerance level is defined as the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely [28].

Environmental Protection Agency guidelines, 3) limiting the application of commercial nitrogen fertilizer to 50 pounds per acre, 4) withdrawal of the chlorinated hydrocarbons aldrin, dieldrin, chlordane, and heptachlor from use on corn, 5) production capacity with no environmental restrictions, and 6) production capacity with a combination of alternatives 1 through 4. A description and indication of the impact of each policy on United States agriculture is detailed in the following subsections.

Soil loss alternative

Soil erosion is a major agricultural pollutant as a result of its own physical characteristics which result in river, lake, and reservoir sedimentation, its function as a transport mechanism for other chemical pollutants such as fertilizers and pesticides, and because of its detrimental effect on the structure and future productivity of agricultural soils.

The soil loss alternative established maximum allowable per acre soil loss values. "The term 'soil loss tolerance' denotes the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely. Soil-loss tolerances range from 1 to 5 tons per acre per year for soils in the United State depending on soil properties, soil depth, topography, and prior erosion." [28].

The soil loss alternative was applied in the model by allowing rotations whose calculated tons of gross soil loss per acre per year was less than the soil-tolerance level for that particular region and soil capability class. Gross soil loss refers to the average annual tons of soil leaving the field. Determination of gross soil loss for rotations in the model is documented in [9]. Briefly, the "Universal Soil Loss Equation" as described by Wischmeier and Smith [28] and a release from the Soil Conservation Service [16] are used for areas east of the Rocky Mountains. For the mountain valleys and West Coast, data are not available to allow application of the soil loss equation. Estimates of tons of soil loss for rotations in these areas were determined in conjunction with SCS questionnaire results [9].

Implementation of the soil loss policy reduces average national per acre soil loss on all cropland by 57 percent. In the unrestricted base solution the average per cropland acre soil loss is 4.6 tons. This was reduced to 2.0 tons under the soil-tolerance levels.

Feedlot runoff control alternative

Feedlot runoff from concentrated livestock operations is the primary point[3] source of agricultural pollution. Wastes that enter streams, rivers, or lakes increase the concentration of plant nutrients in the water, a process referred to as eutrophication. Eutrophication is a natural process that may be beneficial, but in many locations the process has been intensified by man-induced pollution to the point that there is an excessive concentration of nutrients and, as a result, excessive algae and plant growth. Some of the problems associated with eutrophication are

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[3]A point source pollutant is one where the source of the pollutant can be traced to a particular location.

oxygen depletion in the hypolimnetic waters of lakes, interference with recreational uses of water, hindrance of drainage along waterways, and increased costs of water filtration for domestic uses [10].

The Federal Water Pollution Control Act Amendments of 1972 required the United States Environmental Protection Agency to establish effluent limitation guidelines for point source discharges. The proposed E.P.A. guidelines appeared in the Federal Register of September 7, 1973. However, a series of reports by the Economic Research Service of the United States Department of Agriculture on the costs of controlling feedlot runoff had already been initiated before the guidelines were published [2], [4], [8]. These studies were based on guidelines formulated from preliminary E.P.A. information. Quantification of the modifications made to simulate runoff control policies in the model [27] were based on the budgets for beef feeding, swine, and dairy operations developed in these reports.

Nitrogen fertilizer limit alternative

Commercial nitrogen fertilizer usage has increased more than threefold since 1960 [11]. Research has established that runoff and leaching from agricultural lands are significant sources of nitrates in the nation's lakes, rivers, and streams [10]. Allison [1] states.

"Only rarely have ... tests shown nitrogen recoveries in the crop plus soil greater than about 95 percent of the applied nitrogen; values of only 70 to 90 percent are fairly common, and a few are as low as 60 percent ... Such results ... help to explain why nitrogen recoveries in the crop under average field conditions often are no greater than 50 to 60 percent of that applied, even if immobilization is taken into account."

These values although not directly applicable to field studies do indicate that in some circumstances a large proportion of the applied nitrogen may find its way into the nation's waterways.

The potential hazards of increasing nitrate levels are well documented [10] and include the problem of eutrophication discussed earlier and the potential for increased occurrence of methemoglobinemia (nitrate, nitrite poisoning).

As a result of the potential environmental hazards posed by excessive nitrogen fertilization we considered a policy where the application of commerical nitrogen fertilizer was limited to a maximum of 50 pounds per acre of actual nitrogen. The overall impact of the policy was to reduce the average per acre application of nitrogen on all crops from 49.3 to 34.0 pounds. More detailed results are presented in [27].

Removal of chlorinated hydrocarbon insecticides alternative

The fourth policy considered was to simulate the withdrawal of the four chlorinated hydrocarbons aldrin, dieldrin, chloradane, and heptachlor from use on corn in the Corn Belt and Lake States areas.[4] The ban is consistent with recent legislation [5] which suspended the registration of pesticide products containing these chemicals for most agricultural uses. These chemicals are particularly hazardous since due to their persistence they tend to accumulate in the ground, air, and body

[4] States included in these areas are Minnesota, Iowa, Wisconsin, Michigan, Illinois, Indiana, Ohio, Missouri, and parts of Nebraska, South Dakota, and Pennsylvania.

tissues. An annual national human monitoring survey conducted by the E.P.A. in 1971, indicated that based on tissue samples taken during therapeutic surgery or at autopsy that 99.5 percent of all individuals tested had detectable residues averaging 29 p.p.m. of dieldrin in their adipose tissue [5].

The withdrawal is most critical with regard to two potential insect problems: cutworms and a group known as the "first-year corn complex." In simulating the policy, adjustments were made in the model to account for the cost of substitute chemicals and rescue treatments, potential yield reductions where cutworms are a problem or on rotations with corn following a grass crop, reductions in yield due to loss of timeliness, and additional costs associated with replanting if necessary [27].

High export alternatives

To obtain an indication of the productive capacity of United States agriculture with no environmental constraints and under an environmental package consisting of all four policies considered, two additional runs were made. The high export base was designed to measure the unconstrained productive capacity of United States agriculture in 1985 under currently projected technology. The second combination high export and environmental package model was designed to measure the impact of all four environmental constraints on this productive capacity. In both high export solutions the model was first forced to meet the OBERS[5] E' high [26] export demands for 1985 for all commodities except corn, sorghum, wheat, and cotton. These four commodities were constrained to meet the OBERS E' levels of export [26] and then the model was allowed to export all the additional quantities of these grains it could produce. In all other runs the exports were set at the OBERS E' level and no additional exports were allowed. The export levels for the six grains considered in this study under the various policies are given in Table 5.

[5] OBERS is an acronyme referring to the Office of Business Economics, now the Bureau of Economic Analysis, and the Economic Research Service. The term OBERS is commonly used to refer to projections of regional economic activity published by United States Water Resources Council [25].

Table 5. Alternative export levels for the various models

Commodity	1985 OBERS E[a,b]	1985 OBERS E[a] High Export	High Export[c] Base Level	High Export[d] Combination Level
			(Thousand Metric Tons)	
Corn	25,121.91	47,983.24	55,197.57	33,570.80
Sorghum	4,064.27	6,858.38	8,396.15	5,281.21
Barley	435.32	544.32	544.32	544.32
Oats	145.12	275.79	275.79	275.79
Wheat	21,065.03	32,087.43	34,259.58	24,771.66
Soybeans	25,855.03	30,617.78	60,315.29	35,535.69

[a]SOURCE: [26].

[b]Levels used for base, soil loss, nitrogen, livestock, and insecticide levels.

[c]Levels obtained under high export base alternative.

[d]Levels obtained under high export-environmental package combination.

VI. RESULTS OF THE ENVIRONMENTAL AND EXPORT ALTERNATIVES

Impacts on Production and Utilization of Grains

Production of feed, food, and all grains in 1985 under the various alternatives considered is provided in Table 6. Included are the expected 1985 levels of production if the United States experienced the worst weather effect in terms of grain production expected to occur in 10-, 20-, or 40-year periods. The expected levels of production were based on the data in Table 4.

Table 6. United States grain production under various environmental and weather alternatives (1985)

Model and Weather Alternatives[a]	Feed Grain	Food Grain	All Grain
		(Thousand metric tons)	
Base			
Normal	176,315.26	119,933.48	296,248.74
10 year	158,190.05	107,004.65	265,083.37
20 year	147,011.66	98,765.22	244,405.21
40 year	134,563.80	98,105.59	232,466.38
Soil Loss			
Normal	181,563.09	124,828.86	306,391.95
10 year	162,898.40	111,372.30	274,159.51
20 year	151,387.30	102,796.56	252,773.35
40 year	138,568.95	102,110.00	240,425.76
Livestock			
Normal	175,323.21	120,282.51	295,605.72
10 year	157,299.98	107,316.05	264,507.99
20 year	146,184.49	99,052.65	243,874.71
40 year	133,806.67	98,391.09	231,961.80
Nitrogen			
Normal	173,423.95	121,068.26	294,492.21
10 year	155,595.96	108,017.10	263,511.62
20 year	144,600.88	99,699.71	242,956.07
40 year	132,357.15	99,033.84	231,088.03
Insecticide			
Normal	175,487.04	120,508.79	295,995.83
10 year	157,446.97	107,517.94	264,857.06
20 year	146,321,09	99,238.99	244,196.55
40 year	133,931.70	98,576.19	232,267.92

Table 6. (continued)

Model and Weather Alternatives	Feed Grain	Food Grain	All Grain
		(Thousand metric tons)	
High Export			
Normal	202.506.11	163,119.90	365,626.01
10 year	181,688.48	145,535.57	327,162.15
20 year	168,849.59	134,329.23	301,641.45
40 year	154,552.66	133,432.07	286,906.73
Combination			
Normal	195,032.19	125,691.77	320,723.96
10 year	174,982.88	112,142.19	286,983.79
20 year	162,617.84	103,507.17	264,597.26
40 year	148,848.56	102,815.86	251,672.09

[a]Weather alternatives include: expected or normal, worst weather expected in a 10-year period, worst expected in a 20-year period, and worst expected in a 40-year period.

Table 7 gives a breakdown of the demands for grain into domestic intermediate, domestic consumption, and net export categories. The OBERS E' projections [26] of domestic consumption for 1985 were used for all models. The final demand for livestock commodities whose production provide an intermediate demand for grains, is the same for all models, however the intermediate demand for grains varies among models. This is possible since the livestock rations are determined endogenously, allowing considerable substitution among grains in the livestock rations.

Table 7. Utilization of U.S. grain stocks under the alternative models (1985)

Model	Feed Grain	Food Grain	All Grain
	(Thousand metric tons)		
Base			
Produced	176,315.26	119,933.48	296,248.74
Intermediate	127,569.92	46,343.46	173,913.38
Consumed	18,978.54	26,169.96	45,148.5
Net Export	29,766.65	46,920.06	76,686.71
Soil			
Produced	181,563.09	124,828.86	306,391.95
Intermediate	132,817.76	51,738.84	184,556.6
Consumed	18,978.54	26,169.96	45,148.50
Net Export	29,766.65	46,920.06	76,686.71
Livestock			
Produced	175,323.21	120,282.51	295,605.72
Intermediate	126,577.88	47,192.49	173,770.37
Consumed	18,978.54	26,169.96	45,148.50
Net Export	29,766.65	46,920.06	76,686.71
Nitrogen			
Produced	173,423.95	121,068.26	294,492.21
Intermediate	124,678.85	47,978.22	172,657.07
Consumed	18,978.54	26,169.96	45,148.50
Net Export	29,766.65	46,920.06	76,686.71
Insecticide			
Produced	175,487.04	120,508.79	295,995.83
Intermediate	126,741.75	47,418.74	174,160.49
Consumed	18,478.54	26,169.96	45,148.50
Net Export	29,766.65	46,920.06	76,686.71
High Export			
Produced	202,506.11	163,119.90	365,626.01
Intermediate	119,113.77	42,375.05	161,488.82
Consumed	18,978.54	26,169.96	45,148.50
Net Export	64,413.83	94,574.87	158,988.70
Combination			
Produced	195,032.19	125,691.77	320,723.96
Intermediate	136,381.54	39,214.43	175,595.97
Consumed	18,978.54	26,169.96	45,148.50
Net Export	39,671.98	60,307.35	99,979.33

The production and utilization of feed and food grains on a national basis is quite similar for the base, soil loss, nitrogen, and insecticide policies. Even if the United States experiences the worst weather expected in a 40-year period in 1985, domestic demands for all grains could be met and an additional 13 million metric tons could be exported or added to stocks. Individually, feed grains are affected more severely by weather variation than food grains. If the worst weather expected in a 20-year period occurs in 1985, U.S. domestic feed grain production would just satisfy domestic demands. If the worst weather expected in 40-years occurs, feed grain production would fall short of domestic demand by 12 million metric tons. However, in the 40-year case food grain production would exceed food grain demand by 25 million metric tons. In this case livestock producers would probably react to the relative supply and demand of the various grains and adjust ration formulations to substitute food grains and hays for the higher priced feed grains. The most serious potential problem would be in meeting foreign export commitments in excess of 13 million metric tons or commitments for specific grains that might be in particularly short supply as a result of the weather conditions.

There is a significant increase in grain production in the soil loss alternative as compared to the base alternative. All grains production increases by 3.4 percent, feed grains production by 3 percent, and food grains by 4.1 percent, despite constant final demand levels. The soil loss restriction requires farmers to use rotations incorporating a small grain or hay crop in order to reduce per acre soil losses below the soil-tolerance levels. The production of barley, oats, and wheat then increases substantially since the model is forced to include these grains in rotation with the more erosive corn and soybeans. The excess supply of these small grains over domestic consumption and export demands is utilized as livestock feed. A greater total quantity of grains is required to satisfy intermediate feed demands since the feed value of barley and oats is lower than the corn they replace. Table 6 indicates an additional 10 million metric tons of all grains is required to meet intermediate livestock feed demands under the soil loss alternative.

Results for the high export alternative indicate that if U.S. agriculture operates at full capacity in 1985, production of all grains would amount to 365 million metric tons, 23 percent greater than under the base alternative. As a further indication of U.S. capacity, even if the worst weather expected in a 40-year period occurs in 1985, production of all grains will still come within 10 million metric tons of the normal or base production level. This small shortfall could easily be met by substitution of roughages for grain in ruminant rations.

It is important to emphasize that considerable possibilities for substitution exists among grains in production if demand conditions mandate. For example, wheat and sorghum can be grown on most corn and soybean ground while corn can be raised in many areas where wheat is now commonly grown. In most cases, however, total production of all grains is expected to fall as one grain is expanded into fringe areas where its comparative advantage declines.

Combining the four environmental policies together with the high export alternative results in a 12-percent reduction in the production of all grains. However, because of the different approaches used to meet intermediate demands, net exportable grains decline by 37 percent. In the high export alternative, the export potential for corn, sorghum, wheat, and soybeans causes production of these grains to be increased while production of the other grains is decreased. In addition, corn, silages, and hays are substituted for other feed grains in the livestock rations. The latter reduces the total quantity of feed grains required for intermediate use. Hence, additional acres are freed for production of the exportable grains. Combining the environmental policies with the high export alternative increases substantially the quantity of feed grains devoted to intermediate uses. For this combination of alternatives, imposition of the soil loss tolerances and fertilizer limits causes small grains to be substituted for the more erosive corn, soybean, and silage crops. Since there is a limited export demand for barley and oats, these grains are substituted for corn in the livestock rations and corn is freed for the export market.

Weather Variability Impacts

Variations in production are the result of different regional production patterns under the various alternatives. Figures 9 through 20 illustrate the changes in regional production under the soil loss, nitrogen, high export base, and combination alternatives. (Summaries are not made for the feedlot runoff and insecticide alternatives since their impacts on variability are minor.) The actual production of feed, food, and all grains under the various alternatives is listed in Tables 8, 9, and 10.

Regional production patterns change as the regional comparative advantages among crops changes. Comparative advantages are based on the underlying cost and return structure of the crops. For example, the soil loss alternative may require a change in the production process for erosive row crops from straight row to terracing or strip cropping in order to meet the soil erosion limits. The additional conservation practice increases costs without a proportional short run increase in returns. However, a less erosive crop such as wheat may not be affected by the policy. If initially the row crop, say corn, is more profitable than wheat, then corn enjoys a comparative advantage over wheat in this area. If after implementation of the soil loss restriction the profitability of corn falls below that of wheat, then the comparative advantage switches in favor of wheat and production of this crop is expected to replace corn.

Table 11 indicates the relative impact of the various alternatives on the expected variation in grain production. There are several general results of interest indicated in Table 11. First, the variability in feed grain production increases more than the variability in food grain production for all alternatives in comparison with the base alternative. In fact, except for the high export alternative, changes in the variability in food grain production are quite small. Second, the overall impact of a policy alternative on production variability is directly correlated with the "severity" of the policy, where "severity" relates to the relative impact of the alternative on changing regional

Table 8. Feed grain[a] production under the various policy models by states (1985) with 1973-75 average[b] for comparison

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973-75 Average
				(Thousand Metric Tons)				
Maine	84.91	82.83	96.93	234.53	85.29	28.11	206.21	30.53
New Hampshire	2.65	2.57	3.03	7.33	2.67	0.88	6.44	-
Vermont	19.90	19.27	22.72	54.97	19.99	6.59	48.33	-
Massachusetts	10.65	10.28	12.12	29.32	10.66	3.51	25.78	-
Rhode Island	1.33	1.28	1.51	3.66	1.33	0.44	3.22	-
Connecticut	5.31	5.14	6.06	14.66	5.33	1.76	12.89	-
New York	3,242.35	2,834.32	3,255.16	2,839.57	3,370.34	4,506.98	3,153.75	1,164.89
New Jersey	502.04	447.64	504.09	433.27	523.43	704.34	495.95	196.50
Pennsylvania	6,968.86	5,758.89	6,982.69	6,294.29	7,169.14	9,420.84	6,336.23	2,635.21
Delaware	558.39	734.89	561.98	615.78	586.10	738.66	670.05	404.85
Maryland	448.18	1,643.99	496.86	599.20	528.99	456.76	1,086.30	1,277.58
Michigan	7,057.79	6,803.95	6,994.32	5,922.30	6,968.79	7,359.25	5,966.11	3,653.88
Wisconsin	10,147.06	8,618.23	10,085.45	9,604.83	10,471.03	12,655.29	10,407.93	5,522.67
Minnesota	13,387.63	17,044.65	13,295.65	17,822.87	13,807.18	20,016.09	25,016.65	13,230.11
Ohio	15,636.60	9,795.41	15,500.96	15,459.25	15,183.07	17,125.56	9,762.53	7,435.22
Indiana	6,944.44	11,622.50	6,903.22	9,045.73	7,536.64	7,461.93	8,993.14	12,698.39
Illinois	28,077.61	24,046.80	28,043.07	17,774.39	24,690.91	18,951.14	17,678.73	27,687.54
Iowa	25,313.58	18,286.98	25,241.81	25,593.96	25,316.81	33,037.68	30,852.14	28,735.49
Missouri	2,767.64	3,541.30	2,615.79	2,021.94	2,631.10	4,318.30	3,292.92	5,366.27
North Dakota	7,364.30	9,075.56	7,331.17	9,079.85	7,514.50	9,111.19	12,316.81	2,708.66
South Dakota	6,906.66	8,628.35	6,871.64	8,693.29	7,066.49	8,967.63	11,911.30	4,525.42
Nebraska	3,352.03	8,843.34	3,297.80	5,561.70	3,340.16	15,104.52	10,988.23	15,178.90
Kansas	3,550.27	5,552.70	3,687.29	5,855.44	4,035.94	6,072.54	5,477.29	7,906.72
Virginia	740.19	1,541.15	745.28	532.88	761.07	229.28	926.80	1,316.11
West Virginia	133.01	108.66	132.29	148.03	129.60	144.28	94.36	155.24
North Carolina	5,781.82	5,561.29	5,781.82	2,706.58	5,781.82	1,122.23	3,551.48	3,056.31
Kentucky	510.52	1,283.57	447.08	797.92	687.41	350.62	955.83	2,354.65

Table 8. (continued)

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973-75 Average
				(Thousand Metric Tons)				
Tennessee	1,099.58	821.42	852.16	286.60	1,359.79	329.03	552.23	971.36
South Carolina	1,487.38	1,454.11	1,487.38	695.43	1,487.38	291.99	918.23	838.00
Georgia	306.64	2,432.87	306.64	87.29	306.64	365.42	1,267.88	2,546.35
Florida	60.71	246.81	60.71	38.46	60.71	42.87	614.04	442.11
Alabama	323.69	704.67	260.25	83.10	387.51	148.25	248.80	829.54
Mississippi	26.99	157.72	20.64	40.43	33.37	18.21	49.04	193.81
Arkansas	461.74	229.60	360.23	111.32	563.97	125.19	196.28	340.44
Louisiana	29.96	107.82	29.96	45.51	30.08	20.80	47.05	111.40
Oklahoma	983.01	1,168.55	1,027.64	1,490.20	1,128.51	771.31	1,126.91	1,033.91
Texas	9,973.16	9,969.64	9,993.85	9,453.20	9,860.34	9,952.15	8,538.51	11,754.96
Montana	3,937.37	4,302.99	3,937.54	4,049.02	3,931.63	3,003.40	4,887.67	1,237.82
Idaho	1,385.47	1,218.97	1,385.47	1,467.68	1,385.47	1,883.35	755.70	925.50
Wyoming	551.13	610.11	551.14	558.32	550.55	505.77	644.35	221.32
Colorado	2,064.59	2,452.64	2,067.92	2,072.30	2,078.03	2,774.49	2,161.41	1,715.49
New Mexico	493.49	413.63	493.13	412.81	493.49	667.63	492.13	521.10
Arizona	231.45	117.80	231.45	368.81	231.45	87.78	234.18	469.28
Utah	321.50	341.91	331.50	397.29	331.50	344.64	402.86	217.48
Nevada	21.65	23.37	21.74	41.16	22.04	14.13	4.38	17.30
Washington	735.27	637.48	735.27	770.64	735.27	1,018.59	360.34	496.83
Oregon	653.24	577.85	653.47	730.82	654.22	865.29	304.56	281.51
California	1,073.21	1,149.34	1,077.47	1,974.50	1,091.51	724.73	272.10	2,278.93
United States[c]	176,315.26	181,563.09	175,323.21	173,423.95	175,487.04	202,506.11	195,032.19	173,258.76

[a]Corn, grain sorghum, barley, and oats.

[b]SOURCE: [18].

[c]Columns may not sum to United States total due to rounding errors.

Table 9. Food grain[a] production under the various policy models by states (1985) with 1973-75 average[b] for comparison

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973-75 Average
				(Thousand Metric Tons)				
Maine	5.82	6.57	6.13	6.76	5.82	3.00	6.57	--
New Hampshire	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Vermont	13.87	15.66	14.61	16.11	13.87	7.16	15.66	--
Massachusetts	2.68	3.03	2.83	3.12	2.68	1.39	3.03	--
Rhode Island	0.45	0.51	0.47	0.52	0.45	0.23	0.51	--
Connecticut	1.79	2.02	1.89	2.08	1.79	0.92	2.02	--
New York	482.48	301.61	484.97	663.72	437.29	165.40	226.24	195.92
New Jersey	201.45	101.37	201.86	291.54	179.63	53.63	64.02	100.47
Pennsylvania	825.36	495.85	827.65	1,092.47	752.87	347.10	396.85	318.92
Delaware	541.04	221.11	540.85	581.83	514.97	430.93	271.46	167.08
Maryland	1,507.44	525.55	1,504.63	1,265.16	1,492.32	1,708.30	932.43	370.50
Michigan	1,495.09	1,745.09	1,481.29	1,507.43	1,492.35	1,661.58	1,736.19	1,285.10
Wisconsin	158.59	315.38	163.78	173.95	128.78	125.39	275.36	197.76
Minnesota	4,870.50	6,967.34	4,884.47	5,789.60	5,048.63	7,542.67	4,962.73	4,998.48
Ohio	6,702.91	9,393.20	6,728.06	5,880.34	6,709.29	6,993.80	9,580.09	3,921.89
Indiana	11,061.61	10,176.66	11,075.07	9,446.44	10,526.30	12,140.71	10,105.36	4,457.23
Illinois	16,183.08	16,574.09	16,203.71	18,058.30	17,121.77	20,994.62	16,380.73	8,473.50
Iowa	11,823.31	13,239.70	11,794.38	10,971.56	11,805.82	12,943.38	10,741.23	6,396.24
Missouri	4,462.45	4,942.25	4,517.21	4,649.46	4,578.89	5,801.04	5,657.53	4,049.80
North Dakota	7,907.19	11,111.35	7,923.56	9,967.65	8,303.03	15,167.55	8,046.16	6,600.95
South Dakota	1,232.28	1,649.10	1,232.90	1,643.08	1,311.96	2,931.48	1,227.02	1,866.21
Nebraska	4,627.59	4,823.05	4,583.76	4,134.89	4,607.96	5,687.94	5,762.58	3,520.67
Kansas	9,467.31	10,381.12	9,507.32	7,884.80	9,459.47	12,210.12	11,953.73	10,190.73
Virginia	1,767.11	648.37	1,763.82	1,555.25	1,753.63	2,278.00	1,137.23	524.21
West Virginia	36.01	12.44	35.94	29.76	35.72	41.46	22.50	13.40
North Carolina	790.74	676.18	790.74	1,657.43	790.74	3,489.14	844.19	1,120.29
Kentucky	1,164.84	1,033.10	1,173.62	1,007.21	1,110.89	1,318.16	1,057.04	1,076.07

Table 9. (continued)

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973–75 Average
				(Thousand Metric Tons)				
Tennessee	1,272.36	1,241.79	1,321.97	1,335.40	1,230.58	1,580.65	1,477.38	1,248.65
South Carolina	934.12	613.62	930.26	1,590.78	928.42	3,090.31	811.83	797.38
Georgia	3,657.56	782.25	3,620.52	3,368.15	3,602.88	3,852.75	1,407.03	796.24
Florida	1,609.93	330.93	1,594.49	1,489.34	1,587.14	1,694.17	590.61	204.02
Alabama	1,904.35	950.44	1,895.38	1,761.79	1,873.31	2,040.18	1,262.32	757.72
Mississippi	2,835.64	3,430.01	2,835.64	2,645.12	2,835.64	2,898.75	3,280.71	1,691.18
Arkansas	3,673.05	4,405.54	3,829.65	3,968.63	3,487.51	4,606.18	4,899.96	5,303.09
Louisiana	1,856.61	2,226.94	1,856.61	1,753.82	1,856.61	1,934.67	2,129.61	1,123.43
Oklahoma	2,203.45	2,543.97	2,251.86	1,696.55	2,201.93	3,198.61	2,840.12	4,246.47
Texas	1,603.97	1,930.78	1,612.51	1,881.61	1,603.70	2,709.82	2,364.44	2,793.20
Montana	715.61	462.44	704.89	1,454.35	863.96	4,979.76	570.36	3,381.54
Idaho	1,574.42	1,780.48	1,579.57	1,549.69	1,598.04	2,759.48	2,061.63	1,545.00
Wyoming	152.18	120.59	148.07	162.84	151.17	299.96	161.60	170.98
Colorado	1,606.86	1,472.22	1,575.04	1,597.62	1,581.03	2,330.14	1,973.12	1,614.52
New Mexico	--	17.19	--	2.26	--	5.69	53.63	195.08
Arizona	--	--	--	221.91	--	7.95	--	483.99
Utah	238.69	288.17	238.69	377.40	244.80	527.13	522.50	2,562.82
Nevada	94.24	61.52	94.38	57.68	75.38	93.48	78.80	26.50
Washington	3,478.48	3,913.81	3,490.72	3,273.15	3,527.89	5,978.06	4,325.53	3,234.69
Oregon	1,136.16	1,260.55	1,140.08	1,056.70	1,144.22	1,925.20	1,397.48	1,320.29
California	1,759.18	1,158.86	1,761.71	1,084.38	1,408.35	2,005.64	1,619.89	1,198.41
United States[c]	119,933.48	124,826.86	120,282.51	121,068.26	120,508.79	163,119.90	125,691.77	89,979.90

[a] Wheat and soybeans.

[b] SOURCE: [18].

[c] May not sum due to rounding.

Table 10. Production of all grains[a] under the various policy models by states (1985) with 1973-75 average[b] for comparison

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973-75 Average
Maine	90.72	88.80	103.06	241.29	91.10	31.11	212.78	30.53
New Hampshire	2.65	2.57	3.03	7.33	2.67	0.88	6.44	--
Vermont	33.77	34.93	37.33	71.08	33.86	13.75	63.99	--
Massachusetts	13.30	13.31	14.94	32.44	13.35	4.90	28.81	--
Rhode Island	1.77	1.79	1.99	4.18	1.78	0.67	3.73	--
Connecticut	7.10	7.16	7.94	16.74	7.12	2.68	14.91	--
New York	3,724.83	3,135.93	3,740.13	3,503.30	3,807.63	4,672.38	3,379.99	1,360.81
New Jersey	703.49	549.02	705.95	724.80	703.07	757.97	559.97	296.97
Pennsylvania	7,794.22	6,254.74	7,810.34	7,386.76	7,922.01	9,767.93	6,733.07	2,954.13
Delaware	1,099.43	956.00	1,102.83	1,098.61	1,101.07	1,169.60	941.51	571.93
Maryland	1,995.61	2,169.54	2,001.49	1,864.37	2,021.31	2,165.06	2,018.73	1,648.08
Michigan	8,552.88	8,549.04	8,475.61	7,429.73	8,461.14	9,020.82	7,702.30	4,938.98
Wisconsin	10,305.65	8,933.60	10,249.22	9,778.78	10,599.81	12,780.68	10,683.29	5,720.43
Minnesota	18,258.13	24,011.90	18,180.42	23,612.47	18,855.81	27,558.76	29,979.38	18,228.59
Ohio	22,339.50	19,188.62	22,229.03	21,339.59	21,892.36	24,119.36	19,342.62	11,357.11
Indiana	18,006.05	21,799.16	17,978.29	18,492.17	18,062.94	19,602.64	19,098.51	17,155.62
Illinois	44,260.69	40,620.89	44,246.79	35,832.69	41,812.67	39,945.75	34,059.45	36,161.04
Iowa	37,136.89	31,526.68	37,036.18	36,565.52	37,122.63	45,981.06	41,593.38	35,131.73
Missouri	7,230.09	8,483.54	7,133.00	6,671.39	7,209.98	10,119.35	8,950.45	9,416.07
North Dakota	15,271.50	20,186.91	15,254.73	19,047.50	15,817.54	24,278.74	20,362.97	9,309.61
South Dakota	8,138.94	10,277.45	8,104.54	10,336.36	8,378.45	11,899.11	13,138.32	6,391.63
Nebraska	7,979.63	13,666.38	7,881.56	9,696.59	7,948.12	20,792.46	16,750.82	18,699.57
Kansas	13,017.58	15,933.82	13,194.61	13,740.24	13,495.41	18,282.66	17,431.02	18,097.45
Virginia	2,507.30	2,189.52	2,509.10	2,088.13	2,514.69	2,507.28	2,064.03	1,840.32
West Virginia	169.02	121.10	168.23	177.80	165.33	185.74	116.86	168.64
North Carolina	6,572.56	6,237.47	6,572.56	4,364.01	6,572.56	4,611.37	4,395.66	4,176.60
Kentucky	1,675.36	2,316.67	1,620.70	1,805.13	1,798.29	1,668.78	2,012.87	3,430.72

Table 10. (continued)

State	Base	Soil loss	Livestock	Nitrogen	Insecticide	High Export Base	High Export Combination	1973-75 Average
				(Thousand Metric Tons)				
Tennessee	2,371.94	2,063.20	2,174.13	1,622.00	2,590.36	1,909.68	2,029.61	2,220.01
South Carolina	2,421.50	2,067.72	2,417.64	2,286.21	2,415.80	3,382.30	1,730.06	1,635.38
Georgia	3,964.20	3,215.12	3,927.16	3,455.20	3,909.52	4,818.17	2,674.91	3,342.59
Florida	1,670.64	577.09	1,655.20	1,527.79	1,647.85	1,737.03	1,204.64	646.13
Alabama	2,228.04	1,655.11	2,155.63	1,844.89	2,260.82	2,188.44	1,511.12	1,587.26
Mississippi	2,862.63	3,587.73	2,856.28	2,685.54	2,869.01	2,916.96	3,329.75	1,884.99
Arkansas	4,134.79	4,635.13	4,189.88	4,079.95	4,151.48	4,731.38	5,096.23	3,643.53
Louisiana	1,886.57	2,334.75	1,886.57	1,799.33	1,886.69	1,955.47	2,176.66	1,234.80
Oklahoma	3,186.46	3,712.52	3,279.50	3,186.75	3,330.44	3,969.93	3,967.03	5,280.38
Texas	11,577.13	11,900.42	11,606.36	11,334.80	11,464.04	12,661.97	10,902.95	14,548.16
Montana	4,652.98	4,765.43	4,642.43	5,503.38	4,795.60	7,983.16	5,458.03	4,619.36
Idaho	2,959.90	2,999.45	2,965.05	3,017.37	2,983.51	4,642.82	2,817.33	2,470.50
Wyoming	703.30	730.71	699.20	721.16	701.72	805.73	805.95	392.30
Colorado	3,671.45	3,924.85	3,642.97	3,669.92	3,659.07	5,104.63	4,134.53	3,330.01
New Mexico	493.49	430.82	493.13	415.07	493.49	673.32	545.76	716.18
Arizona	231.45	117.80	231.45	590.72	231.45	95.73	234.18	953.27
Utah	570.19	630.09	570.19	774.69	576.30	871.77	925.36	2,780.30
Nevada	115.89	84.89	116.12	98.83	97.43	107.62	83.18	43.80
Washington	4,213.75	4,551.29	4,225.99	4,043.79	4,263.16	6,996.64	4,685.88	3,731.52
Oregon	1,789.40	1,838.40	1,793.55	1,787.52	1,798.44	2,790.49	1,702.04	1,601.80
California	2,832.39	2,308.20	2,839.18	3,058.88	2,499.86	2,730.37	1,892.00	3,477.34
United States[c]	296,248.74	306,391.95	295,605.72	294,492.21	295,995.83	365,626.01	320,723.96	263,238.66

[a] Corn, grain sorghum, barley, oats, wheat, and soybeans.

[b] SOURCE: [18].

[c] Columns may not sum to U.S. total due to rounding.

production with respect to the base alternative. These results as well as their underlying causes are discussed further under the individual alternative below.

Table 11. Estimated relative increase in weather variation in grain production under the various alternatives (base alternative = 100)

Policy	Feed Grains	Food Grains	All Grains
Base	100.00	100.00	100.00
Soil Loss	104.04	100.09	102.41
Livestock	100.03	100.00	100.01
Nitrogen	101.34	100.19	101.33
Insecticide	100.18	100.07	100.28
High Export	102.39	101.84	102.79
Combination	104.54	100.68	102.99

Soil loss alternative

Regions with high levels of sediment carried by streams are delineated in Figure 8. These regions provide a rough indication of areas where soil erosion is a major problem. As might be expected under the soil loss alternative, as compared to the base alternative, the more erosive row crops shift out of the more erosive areas and are replaced by less erosive small grains and hays. For example, corn and soybeans shift out of the Corn Belt and Southeast into the Plains and Lake States, while the production of wheat, barley, and oats increases in the more erosive areas of the Southeast, Corn Belt, and Delta States under the soil loss alternative. In addition, this alternative causes more corn and soybeans to be produced in rotation with barley and oats as evidenced by increased production of oats, barley, corn, and soybeans in the Plains.

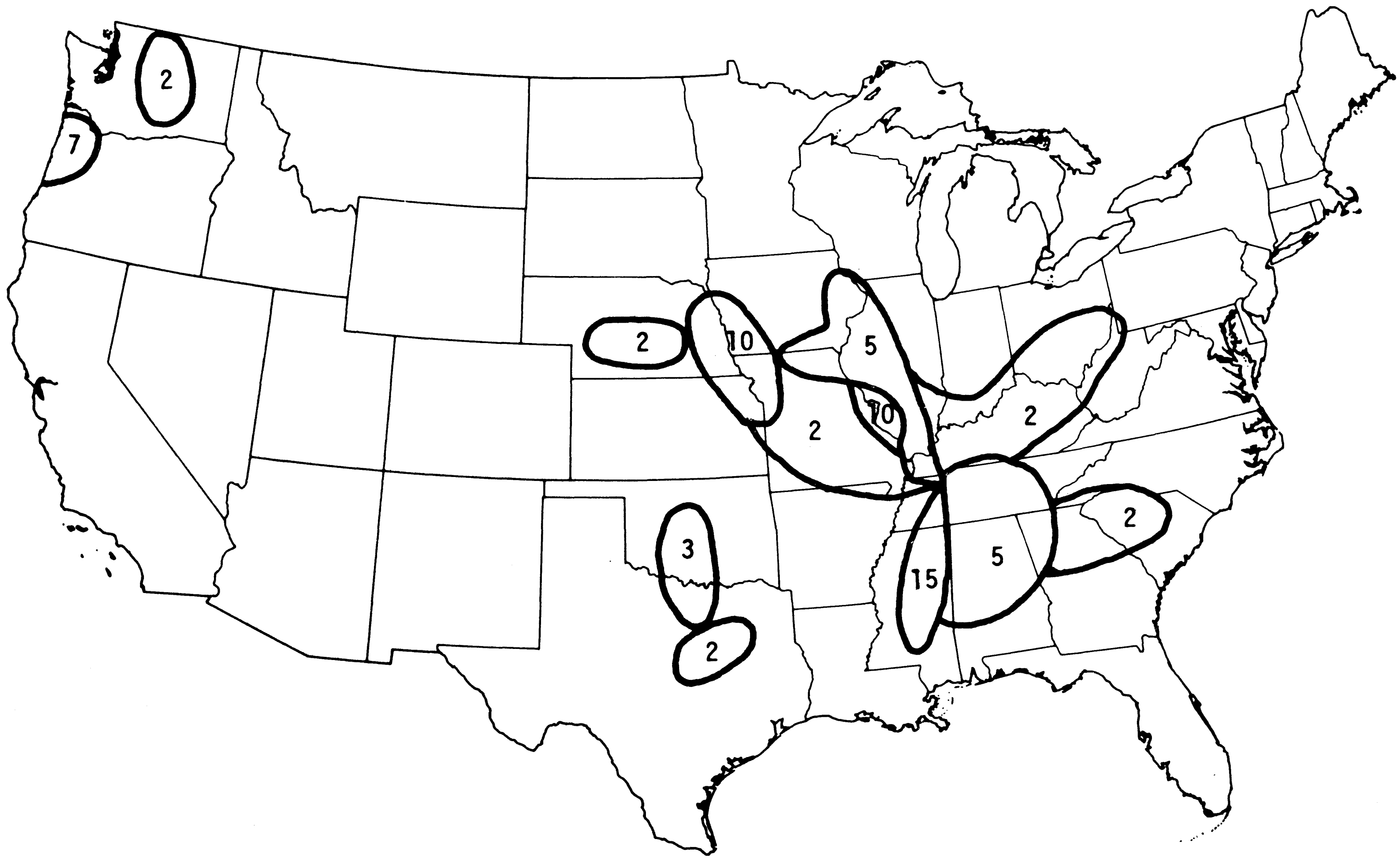

Figure 8. Generalized regions of sediment carried by streams, expressed in tons/ha per year[a]

[a]SOURCE: [17].

As Table 11 indicates, production variability under the soil loss restriction increases by 4 percent for feed grains but by less than 1 percent for food grains. Overall, production of feed grains decreases in the Corn Belt and Lake States and increases in the Plains and Southeast, Figure 9. Comparing Figure 9 to Figure 5 indicates that overall feed grain production increases in areas of relatively high weather variability and decreases in areas of relatively low weather variability.

The impacts of changes in the location of food grain production under the soil loss alternative are not as clear. Soybean production shifts out of the Southeast and Corn Belt into the Plains while wheat shifts out of the Plains into the Delta States and Corn Belt. Overall, there was a net decrease in production of food grains in the Southeast and net increases in the Delta States, Plains, Corn Belt, and Lake States, Figure 10. The net effect on expected weather variability is insignificant.

The combined food and feed grain effect is illustrated in Figure 11. The overall impact on weather variability is quite similar to the feed grain effects (Figure 9) since the food grain impacts are insignificant.

<u>Nitrogen alternative</u>

Table 12 lists the total usage of nitrogen by states in 1974. These data indicate areas where the 50 pounds per acre limit on commercial nitrogen application is likely to be restrictive in crop production. Corn is the most nitrogen intensive crop considered, with an average national application rate of 102.5 pounds per acre fertilized in 1974. The 50 pounds restriction generally is not limiting for wheat, oats, barley, sorghum, and soybeans.

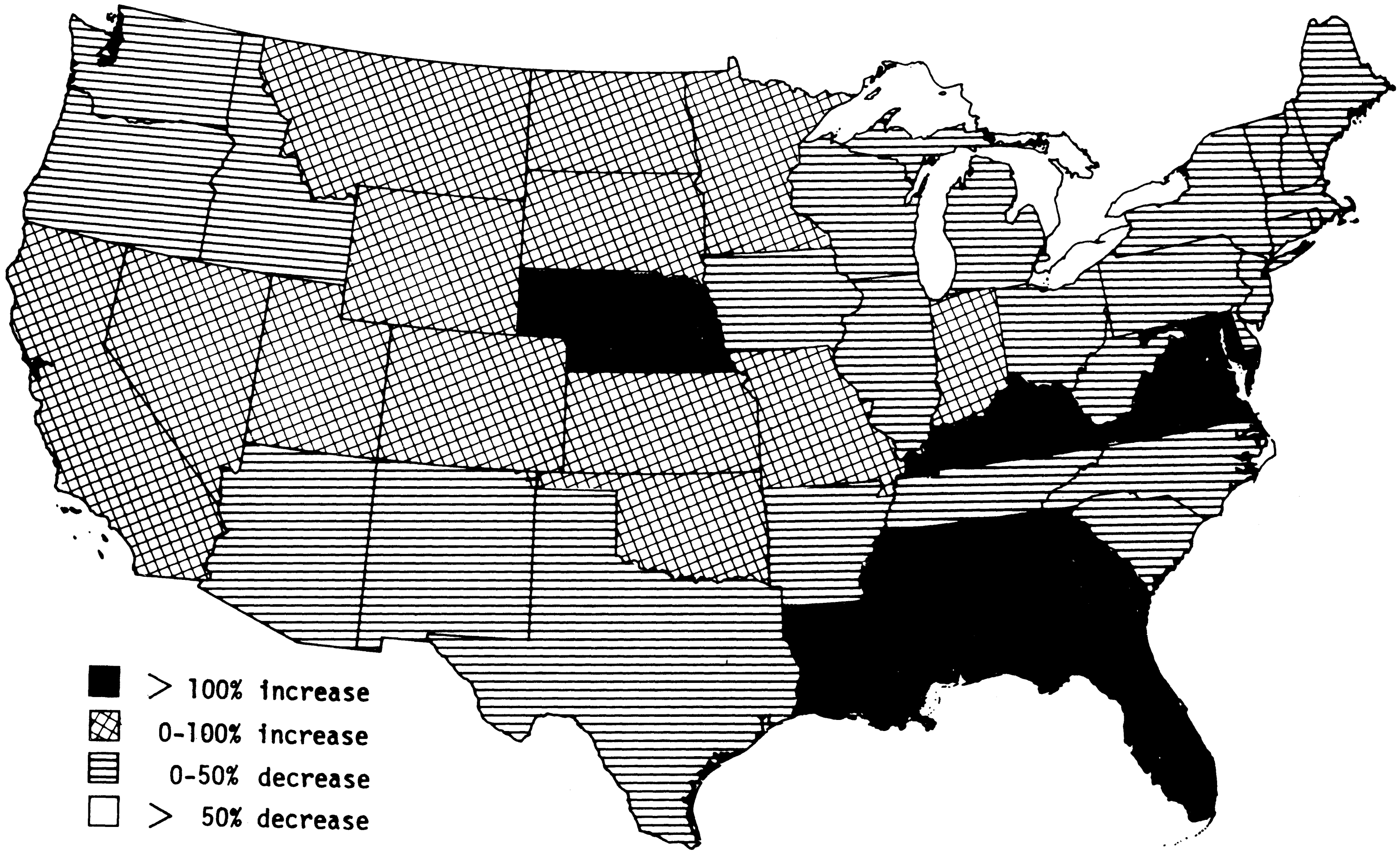

Figure 9. Percent change in feed grain production under the soil loss alternative

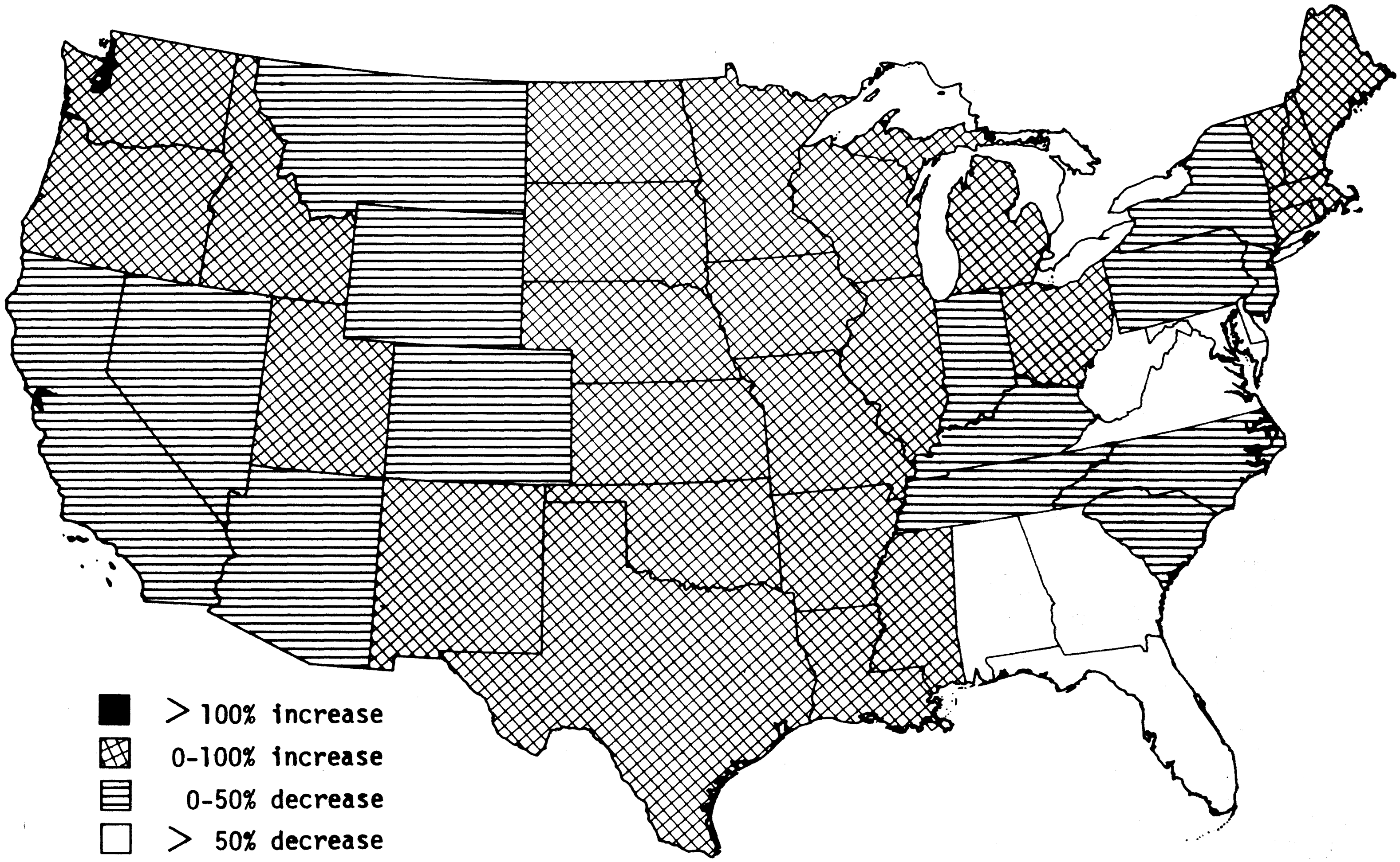

Figure 10. Percent change in food grain production under the soil loss alternative

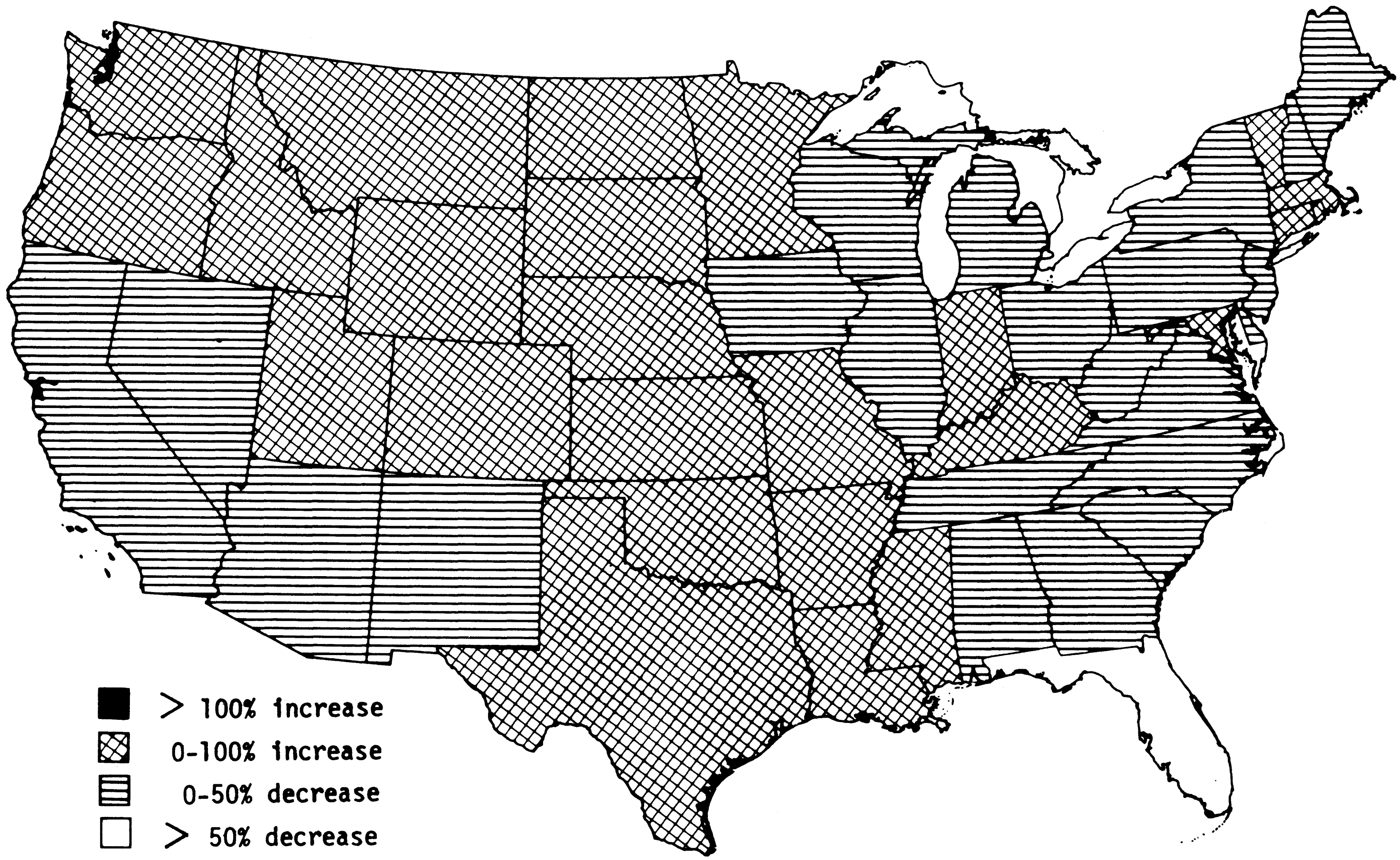

Figure 11. Percent change in all grain production under the soil loss alternative

Table 12. Use of nitrogen as fertilizer by States, year ended June 30, 1974 Total nitrogen use and per acre rates for corn,[b] soybeans,[c] wheat,[d] and cotton,[e] in selected states[a]

State	1974 use 1,000 tons of N	Corn: Percent acres receiving N	Corn: Pounds N per acre	Soybeans: Percent acres receiving N	Soybeans: Pounds N per acre	Wheat: Percent acres receiving N	Wheat: Pounds N per acre	Cotton: Percent acres receiving N	Cotton: Pounds N per acre
Maine	16.7								
New Hampshire	2.6								
Vermont	7.1								
Massachusetts	9.0								
Rhode Island	2.6								
Connecticut	8.2								
New York	86.8								
New Jersey	24.3								
Pennsylvania	88.0	97.4	71.1						
Delaware	16.5	96.2	112.4						
Maryland	46.9	100.0	92.5						
District of Columbia	.9								
Michigan	155.0	98.0	72.4			96.8	37.7		
Wisconsin	139.6	98.2	61.7						
Minnesota	410.3	93.6	83.0	17.6	14.5	91.8	52.3		
Ohio	288.4	98.8	90.4	46.8	12.9	96.9	40.1		
Indiana	354.1	99.4	101.9	48.8	9.8	98.6	53.4		
Illinois	738.3	95.5	113.2	11.9	10.5	95.8	57.0		
Iowa	750.5	89.7	101.8	6.5	8.7				
Missouri	351.2	93.4	116.7	11.9	16.7	98.8	53.4	97.2	60.2
North Dakota	132.6					63.1	20.8		
South Dakota	104.4	59.3	47.4			42.4	23.0		
Nebraska	585.9	93.7	130.9	7.4	27.3	72.2	45.2		
Kansas	563.7	92.9	139.7	12.2	55.2	68.2	48.9		
Virginia	80.0	98.3	133.3						
West Virginia	8.7								
North Carolina	217.3	100.0	132.9	56.9	16.5			100.0	69.8

Table 12 (continued)

State	1974 use 1,000 tons of N	Corn: Percent acres receiving N	Corn: Pounds N per acre	Soybeans: Percent acres receiving N	Soybeans: Pounds N per acre	Wheat: Percent acres receiving N	Wheat: Pounds N per acre	Cotton: Percent acres receiving N	Cotton: Pounds N per acre
Kentucky	121.2	100.0	96.5						
Tennessee	115.8			38.0	14.5			100.0	65.8
South Carolina	104.3			59.5	21.1			100.0	101.3
Georgia	283.2	99.1	124.2					100.0	118.8
Florida	216.7								
Alabama	174.1							100.0	99.5
Mississippi	228.0			16.5	23.0			100.0	103.2
Arkansas	151.0			20.0	16.1			97.8	68.0
Louisiana	151.4			16.8	18.6			97.9	68.6
Oklahoma	210.5					65.4	53.5	47.2	21.2
Texas	800.4					64.7	81.8	54.6	48.3
Montana	45.9					36.8	13.0		
Idaho	125.4					72.1	69.1		
Wyoming	17.6								
Colorado	118.6	92.2	157.8			8.1	35.4		
New Mexico	34.4							52.0	48.9
Arizona	108.0							97.1	122.9
Utah	25.6								
Nevada	4.8								
Washington	205.2					86.5	69.4		
Oregon	98.7					81.7	69.2		
California	542.8							83.5	103.6
Total	9,073.2	93.6[2]	102.5[2]	21.9[3]	14.7[3]	66.3[4]	46.5[4]	78.7[5]	77.6[5]

[a] SOURCE: [5]

[b] Survey of 17 states representing 91 percent of total wheat acres harvested in U.S. in 1974.

[c] Survey of 14 states representing 85 percent of total soybean acres harvested in U.S. in 1974.

[d] Survey of 17 states representing 91 percent of total wheat acres harvested in U.S. in 1974.

[e] Survey of 14 states representing virtually all cotton acres harvested in U.S. in 1974.

Limiting per acre applications of nitrogen to 50 pounds results in reduced yields of nitrogen intensive crops, an increased acreage of nitrogen intensive crops, a substitution of less nitrogen intensive grains for corn in livestock rations, an increase in rotations including a legume crop, and a substitution in production of less nitrogen intensive crops for the more nitrogen intensive crops. The 50 pounds limit reduces U.S. average corn yields 14 percent and increases total corn acres in the United States by 10 percent. The acreages of wheat, sorghum, oats, and barley also increase as their comparative advantage relative to corn increases with lower nitrogen rates and yields for corn. The increase in production of wheat, oats, sorghum and barley, coupled with the decrease in corn production, induces changes in the livestock ration formulations. Intermediate use of corn in livestock rations falls from 73 percent of the total grain fed to 57 percent as compared to the base alternative. Looking at the individual grains, intermediate use of corn falls 12 percent while sorghum increases by 66 percent, oats by 72 percent, and barley by 64 percent. Because of the lower feed value of these grains relative to corn, a larger total quantity of grain is required to meet the energy needs of the livestock sector.

The nitrogen alternative has a moderate impact on the variability of feed grain production but a very small impact on variability of food grain production, Table 11. Figure 12 illustrates the shifts in feed grain production which occur under the nitrogen alternative, in comparison with the base alternative. The majority of the 10 percent increase in corn acreage occurs in the Great Plains as corn production shifts out of

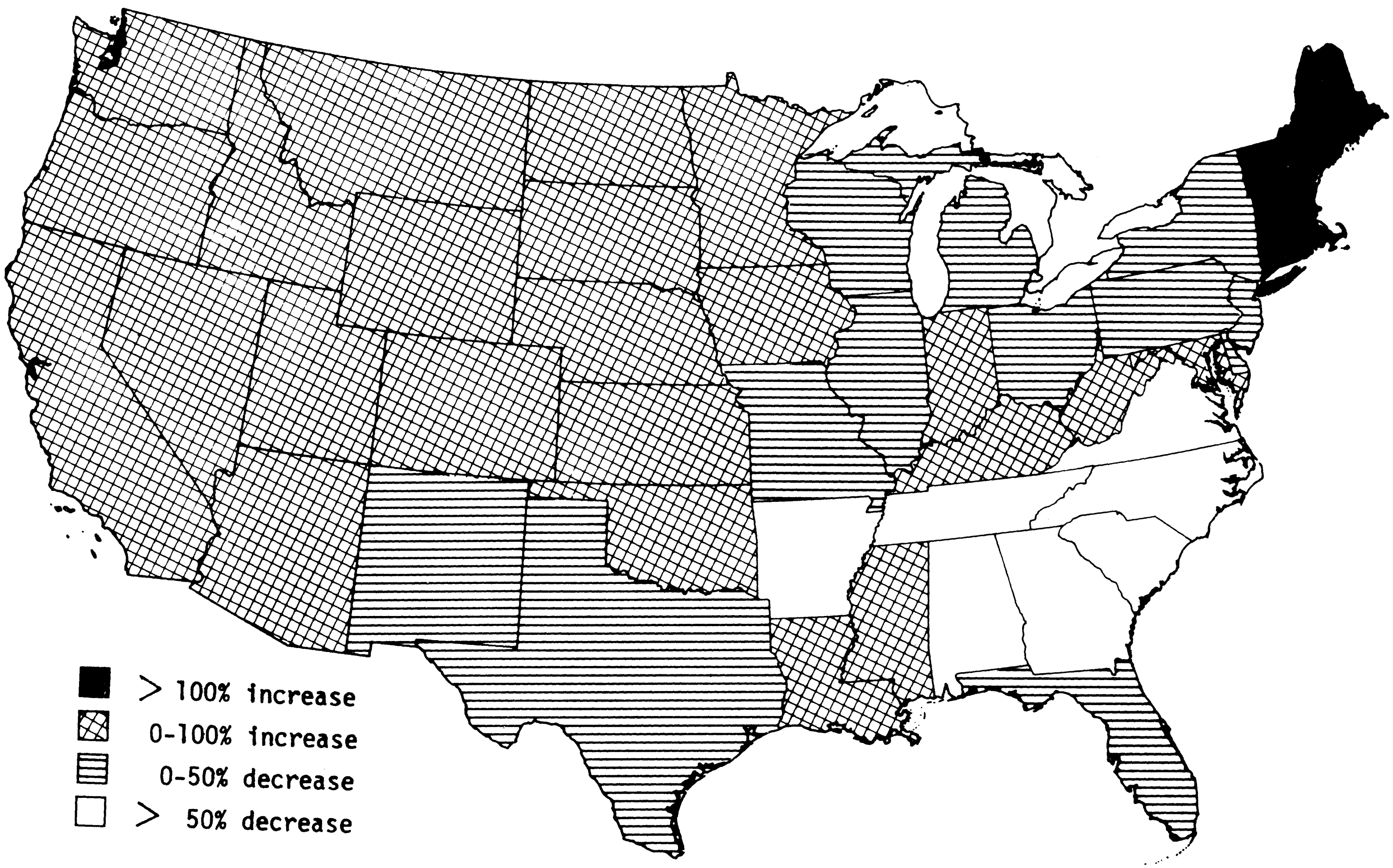

Figure 12. Percent change in feed grain production under the nitrogen alternative

the Corn Belt and Southeast. This shift in production results as yields are lowered in the Corn Belt and Southeast, regions where nitrogen application rates typically are among the highest in the nation, Table 12, rather than from a reduction in the number of acres of corn raised in these regions. Production of oats, barley, and sorghum increases mainly in the Plains and Corn Belt areas.

Figure 12 illustrates the net decrease in feed grain production in the Southeast, Southern Plains, Corn Belt and Lake States and the net increase in the Northern Plains, Mountain, and West Coast regions under the nitrogen restriction alternative as compared to the base alternative. Comparing Figure 12 with Figure 5, the major factor behind the increase in variability of feed grain production is the greater production in the Northern Plains under the nitrogen restriction alternative.

The effect of the nitrogen alternative on food grains is illustrated in Figure 13 and the net effect on all grains in Figure 14. The shifts in wheat and soybeans are similar to those in the soil loss policy.

High export alternative

The high export alternative results in a general expansion in the production of all grains, Figure 15. This alternative responds to increased grain export levels by shifting the production of corn, soybeans, wheat, and sorghum to areas with the greatest comparative advantage in the production of each crop. Regional specialization emphasizes corn and soybeans in the Corn Belt, wheat and soybeans in the Southern Plains, Delta States, Southeast, and Appalachian States, and corn and wheat in the Lake States and West Coast.

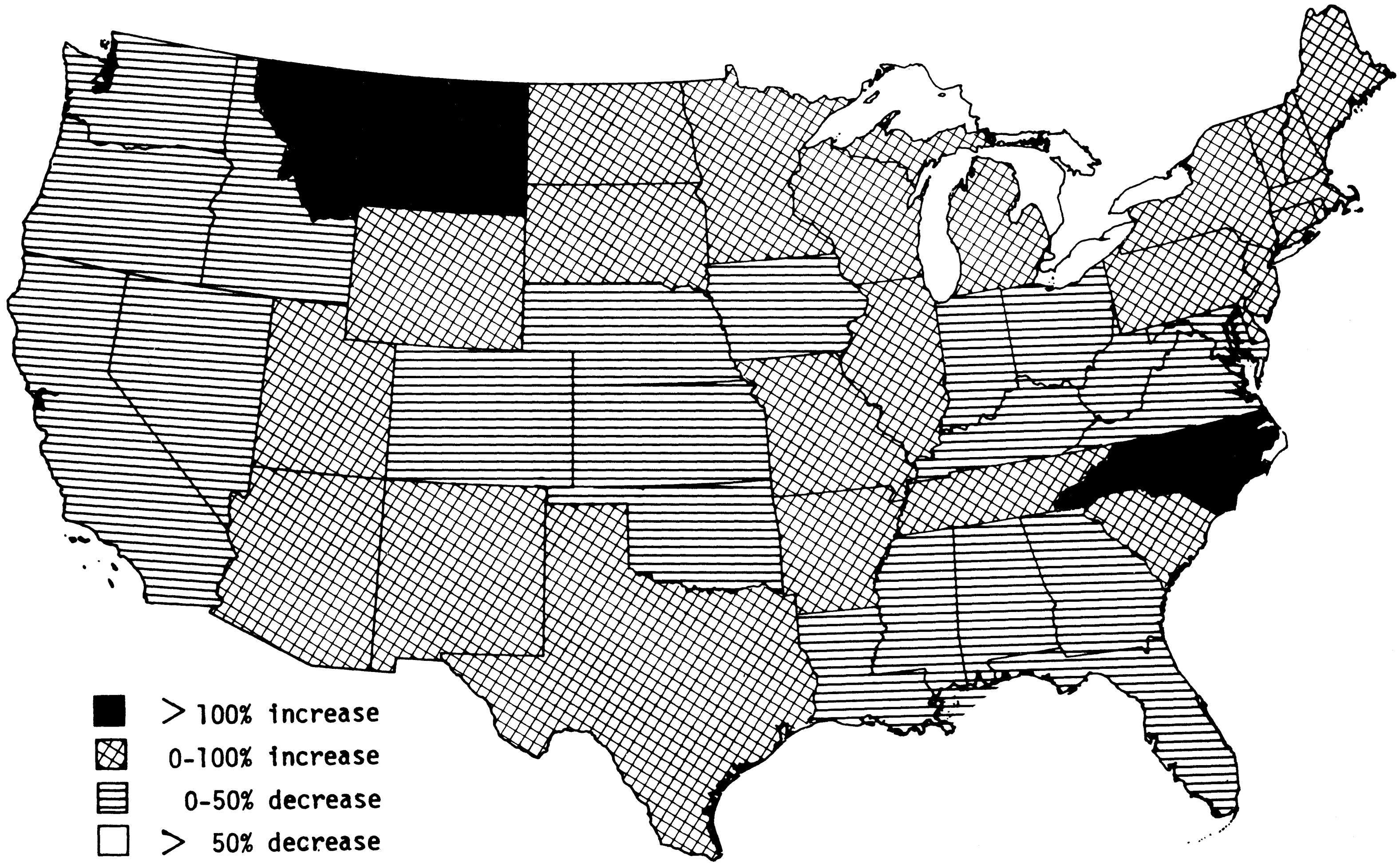

Figure 13. Percent change in food grain production under the nitrogen alternative

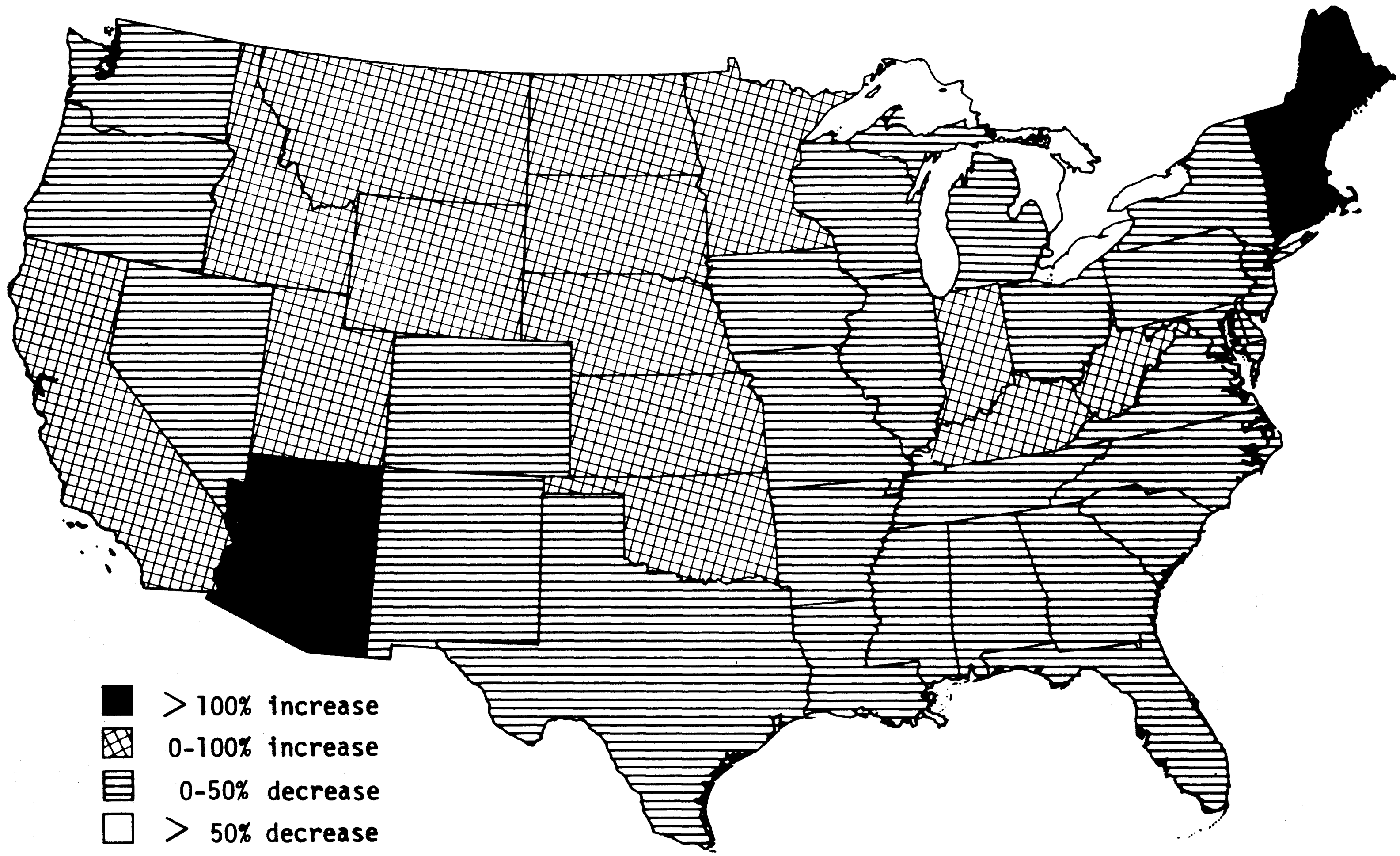

Figure 14. Percent change in all grain production under the nitrogen alternative

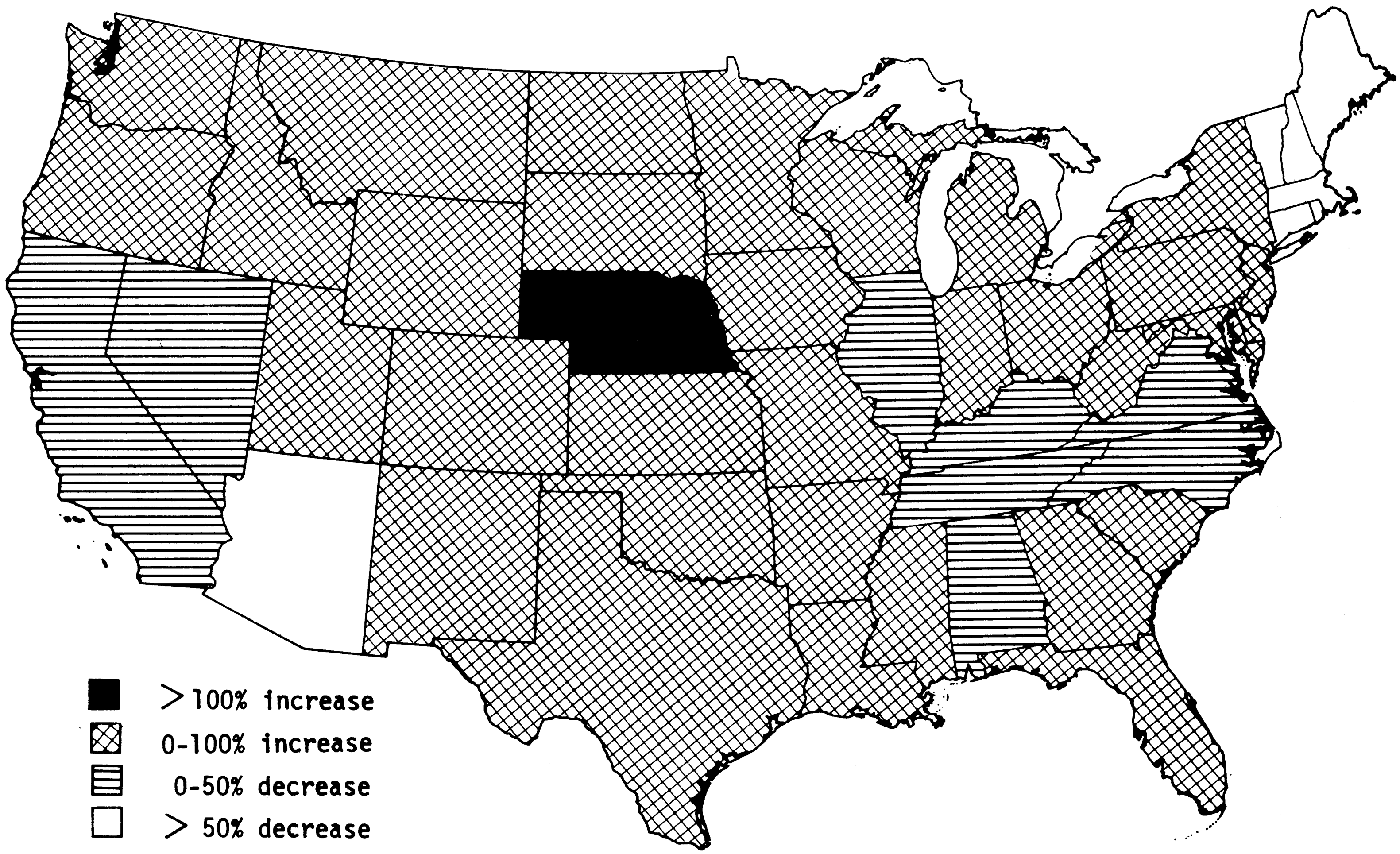

Figure 15. Percent change in all grain production under the high export alternative

The result of the increased export demand is a 23 percent increase in all grain production, Table 6. Of this 69.4 million metric ton increase, one-third is in the four plains states North Dakota, South Dakota, Nebraska, and Kansas, Table 10. The increase occurs in both food and feed grains indicating that a large amount of additional cropland is brought into production.

The livestock rations also change under the high export alternative. Corn is substituted for wheat, oats, barley, and sorghum since its higher feed value allows the energy requirements of the livestock sector to be met with 12 percent less total grain. Individually, corn increases from 73 percent to 89 percent of the total grain used in livestock rations, while barley, oats, and wheat each decreases approximately 80 percent from levels of the base alternative.

As Table 11 indicates, the high export alternative is the only one where the relative increase in variability of food grains production is significant. Although food grain production increases generally over the nation, the largest increases occur in the Southern Plains, Delta States, Southeast, and the Northern Plains, Figure 16. As Figure 6 indicates, these are the areas of greatest variability in food grain production.

The increase in variability of feed grain production is primarily the result of the large increase in acreage in the Plains States and Missouri under the high export alternative. The impact of this increased acreage on production variability is illustrated in Figure 17.

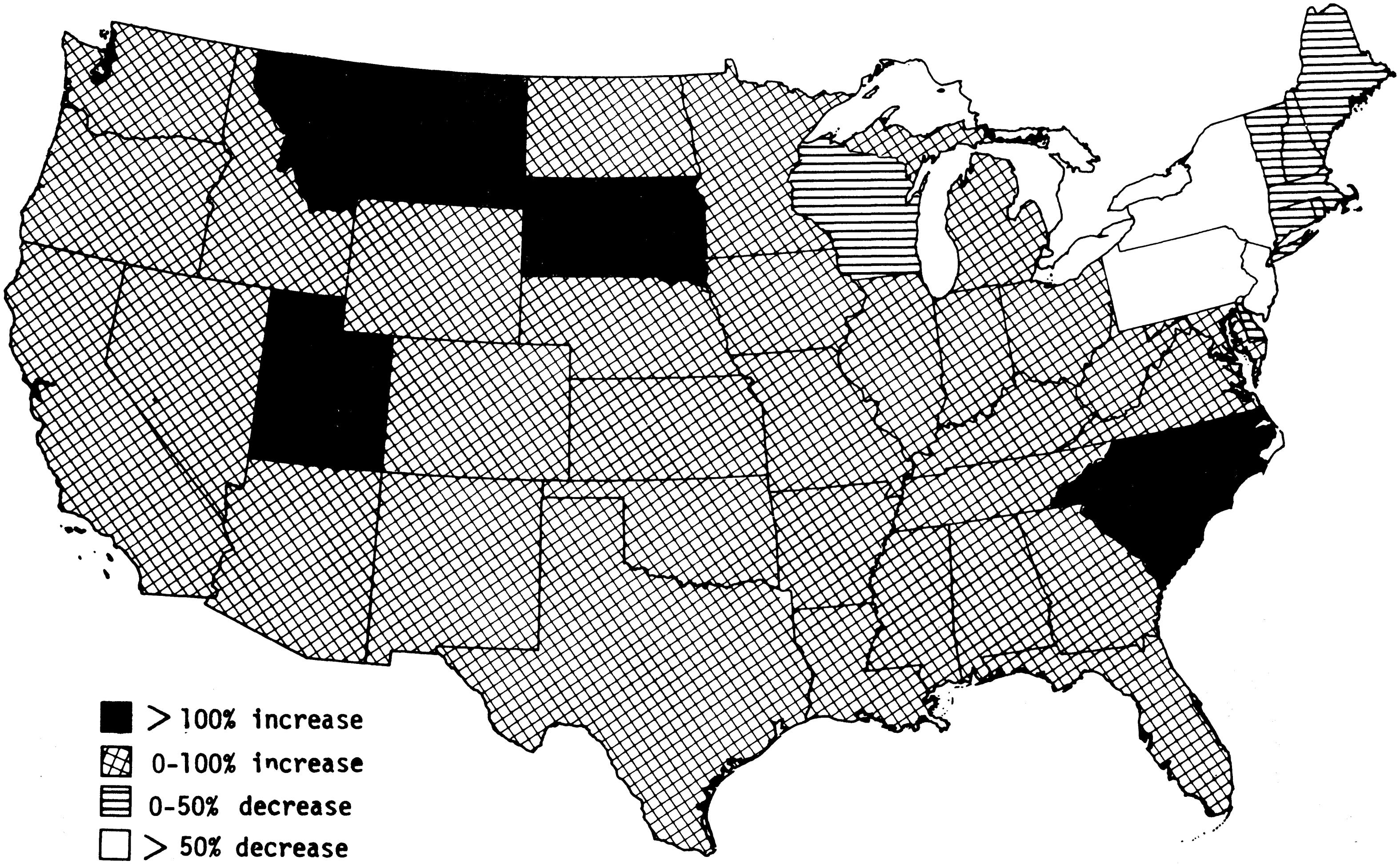

Figure 16. Percent change in food grain production under the high export alternative

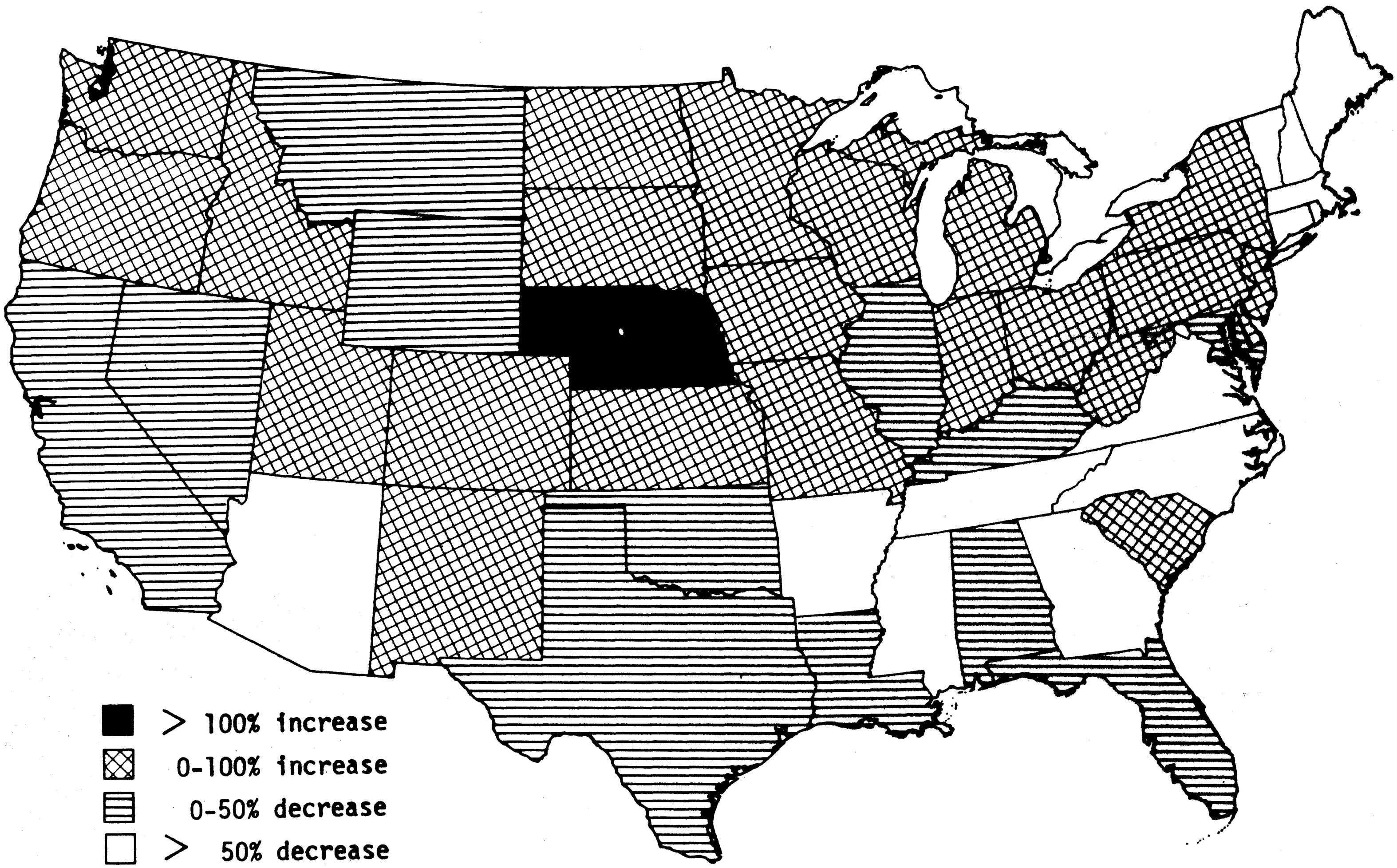

Figure 17. Percent change in feed grain production under the high export alternative

Combined high export and environmental alternative

As suggested by the results of the individual policies, the soil loss restriction and high export demands have the greatest impact on interregional land use and crop production variability. The soil loss restriction forces row crops, corn and soybeans out of the Southeast and Corn Belt into the Northern and Southern Plains. In addition, in the combined high export and environmental alternative regions were unable to specialize to the extent they did in the high export alternative since the soil loss restriction eliminated many of the continuous row crop rotations. Figures 18, 19, and 20 illustrate the regional production shifts in feed, food, and all grains under the combined high export and environmental alternative.

VII. INTERACTION BETWEEN OPTIMAL GRAIN STOCK RESERVES AND WEATHER

Policy makers may desire to maintain a stock of grain reserves to offset occasional shortages caused by unfavorable weather [3]. The three policy alternatives considered in this analysis are: (1) grain reserve to meet 90 percent of domestic shortfalls and 60 percent of foreign shortfalls (policy I), (2) grain reserve to meet 90 percent of domestic shortfalls and 75 percent of foreign shortfalls (policy II), and (3) grain reserve to meet 90 percent of domestic shortfalls and 60 percent of foreign shortfalls in the same year (policy III).

Demand for grain is divided into two general categories, food grains for human consumption and feed grains for livestock consumption. However,

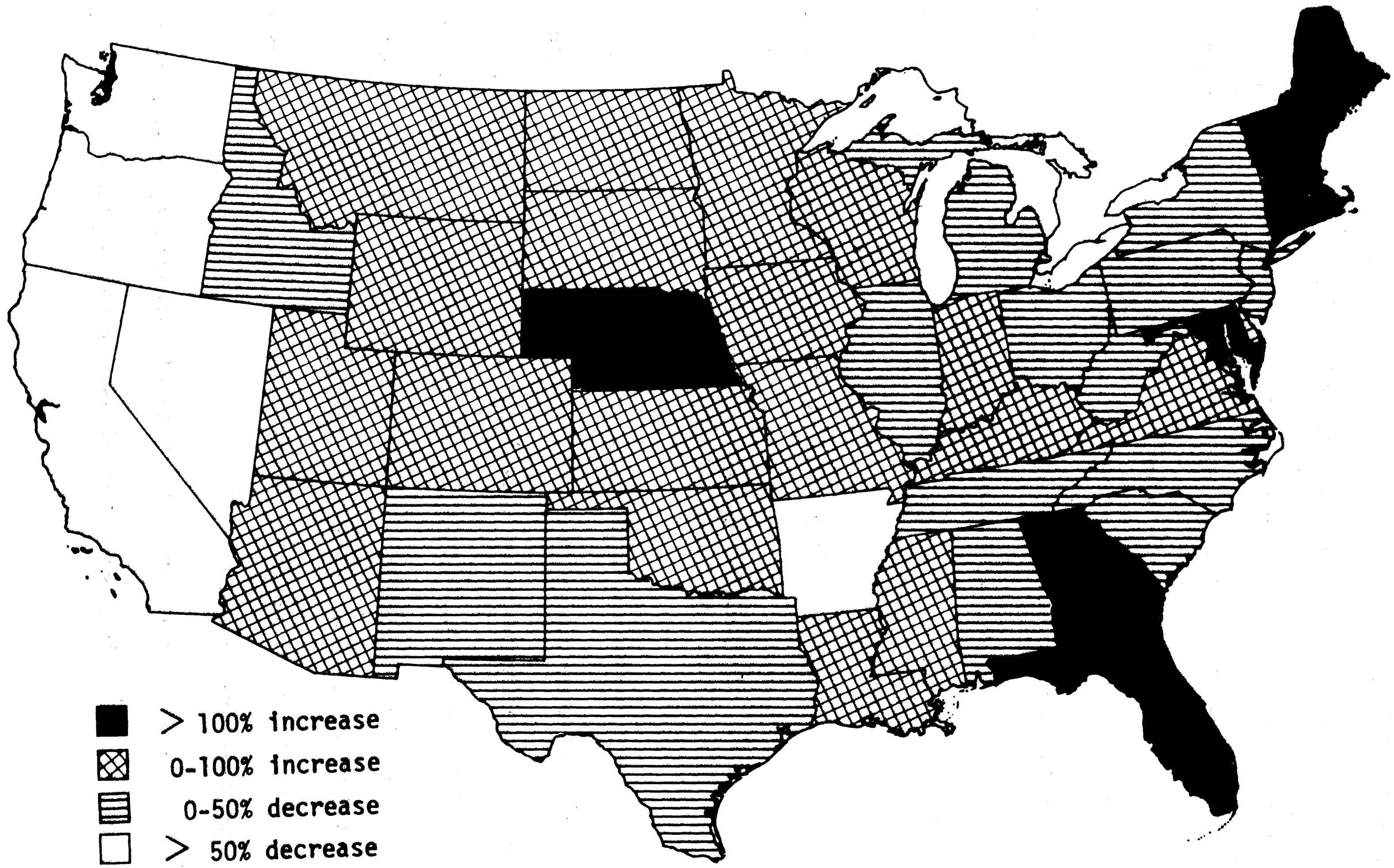

Figure 18. Percent change in feed grain production under the combined high export and environmental alternative

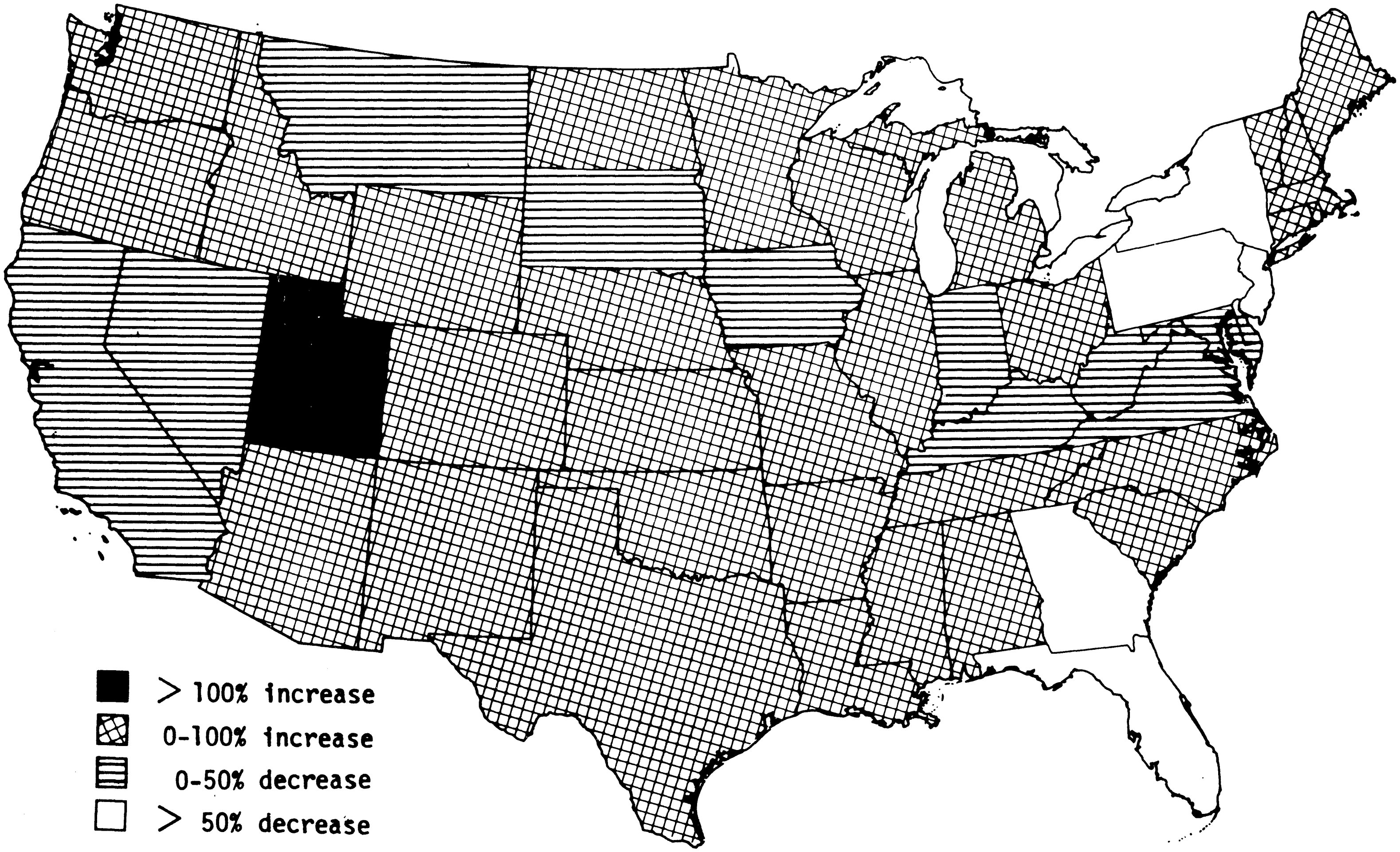

Figure 19. Percent change in food grain production under the combined high export and environmental alternative

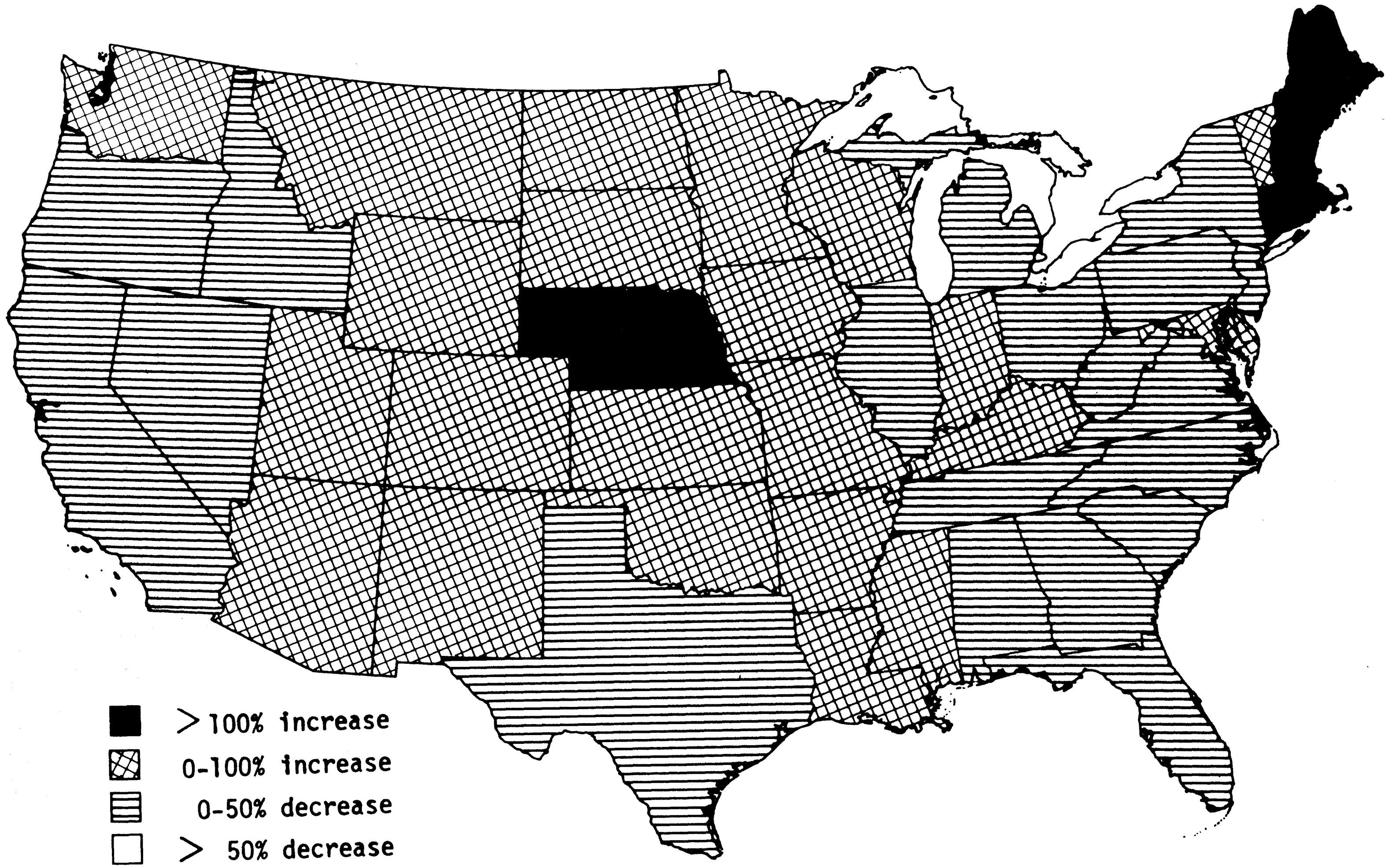

Figure 20. Percent change in all grain production under the combined high export and environmental alternative

for this analysis, food and feed grains are considered substitutes when shortages occur. These three policies will be evaluated under the three weather conditions discussed earlier; namely the worst weather expected in 10-, 20-, and 40-year periods.

Alternative Levels of Grain Stock Reserves

Grain reserves to meet 90 percent of U.S. domestic shortfalls and 60 percent of foreign shortfalls: policy I

Food, feed and all grain reserves for a 10-year period Table 4 indicates that the worst weather expected in a 10-year period results in a decrease of 10.5 percent in all grain production, a 10.3 percent decrease in feed grain production, and a 10.8 percent decrease in food grain production in the United States. Table 13 lists the changes in contingency stocks, the portion of the stocks used to cover shortfalls during the period, and the storage costs associated with alternative grain reserve levels. High reserve levels allow a greater coverage of shortfalls, but only at a higher per unit used storage cost.

During the two 10-year periods from 1952 to 1971, the average total grain shortfall in both the United States and the world was 192 million metric tons. A reserve level equal to 8 percent of U.S. production trend during this period results in 174 million metric tons in reserve and 51 percent of the total shortfalls covered. A 22 percent reserve level allows for more than 90 percent of the shortfalls to be covered during the same period. However, storage costs per ton used are \$11.30 at the 22 percent level and only \$6.30 at the 8 percent level. The difference in storage

Table 13. All grains: estimated grain shortfalls in the world and U.S. grain production, grain stocks reserved and used, and storage costs to meet policy I

	Ratio of U.S. domestic grain stock reserve to production trend (percent)								
	8%	10%	12%	14%	16%	18%	19%	20%	22%
	(million metric tons)								
Grain shortfalls[a]	192	192	192	192	192	192	192	192	192
Contingency stocks[b]	174	218	261	305	348	391	413	435	478
Stocks used[c]	98	113	127	138	149	157	161	164	171
Grain shortfalls[d] uncovered	94	79	65	54	43	35	31	28	21
	(dollar)								
Storage costs[e] (million)	615	791	966	1,115	1,343	1,536	1,642	1,724	1,930
Storage costs per ton used	6.3	7.0	7.6	8.1	9.0	9.8	10.2	10.5	11.3

[a]Sum of annual U.S. and world deviations over the period.
[b]Sum of annual U.S. grain stocks reserved during this period.
[c]Sum of U.S. stocks used to meet U.S. and world shortfalls.
[d]Sum of annual shortfall uncovered by U.S. stocks.
[e]Computed at $4.91 per ton on ton-years reserve (13).

costs reflects the smaller percentage use of the reserves on hand at the 22 percent level.

A contingency stock level of 14 percent (Table 13) of the U.S. production trend is sufficient to meet the requirements of policy I; 305 million metric tons are held in reserve with 45 percent of the stocks used to meet shortfalls during the 10-year period. Storage costs to hold the reserve are $8.10 per ton used.

Table 14 breaks the reserves down into food and feed grain components. Under policy I, a reserve level equal to 41 percent of the U.S. food grain production is required to meet food grain shortfalls; but a level equal to only 10 percent of the U.S. feed grain production is required to meet feed grain shortfalls. The total world food grain shortfalls accumulated during the period are 162 million metric tons, 86 percent higher than the total world feed grain shortfall of 87 million metric tons. Under policy I, the U.S. contingency stocks of food grains during the period are 238 million metric tons with 43 percent of the total used to meet food grain shortfalls. Likewise, the U.S. contingency stocks of feed grains during the period are 138 million metric tons with 52 percent of the stocks used to meet feed grain shortfalls. As a result of the higher food than feed grain requirement, the storage costs of food grains per ton used are $9.00 while those of feed grains are only $6.90.

Food, feed, and all grain reserves for a 20-year period The worst weather expected in a 20-year period results in a decrease of 17.5 percent in U.S. grain production, 16.6 percent in U.S. feed production, and 17.7

Table 14 . Estimated grain shortfalls, contingency stocks reserved and used, and storage costs of U.S. domestic grain stocks meeting policy I under conditions of the worst weather expected in 10-, 20-, and 40-year periods

Ratio	All grains			Food grain			Feed grain		
	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.
Ratio of desirable U.S. domestic grain reserve to production trend (%)	14%	16%	19%	41%	42%	43%	10%	12%	14%
Grain shortfalls in million metric tons[a]	192	383	754	162	323	628	87	173	353
Grain reserves in million metric tons[b]	305	626	1,486	237	485	993	138	331	772
Stock used in million metric tons[c]	138	279	535	102	208	404	72	154	306
Grain shortfalls uncovered in million metric tons[d]	33	104	219	60	115	224	15	19	47
Storage costs in million dollars[e]	1,115	2,388	5,983	912	1,914	3,884	501	1,249	3,039
Storage costs per ton used in dollars	8.4	8.6	10.0	8.9	9.2	9.6	6.9	8.1	9.9

[a]Sum of annual U.S. and world deviations over the period.
[b]Sum of annual U.S. grain stocks reserved during this period.
[c]Sum of U.S. stocks used to meet U.S. and world shortfalls.
[d]Sum of annual shortfall uncovered by U.S. stocks.
[e]Computed at $4.91 per ton on ton-years reserve (5).

percent in U.S. food grain production (Table 14). Total world grain shortfalls accumulated during the period are 383 million metric tons, 136 percent higher than during a 10-year period. Consequently, the levels of grain reserves required to meet grain shortfalls are higher in a 20-year period than in a 10-year period. A contingency stock of 16 percent of U.S. grain production trend covers 90 percent of U.S. domestic grain shortfalls and 60 percent of foreign shortfalls. Contingency stocks during the period are 626 million metric tons, with 45 percent of the stocks used to meet shortfalls. Storage costs are $8.60 per ton used (Table 13).

Table 13 indicates that the food grain requirement is equal to 42 percent of U.S. food grain production and the feed grain requirement equal to 12 percent of U.S. feed grain production. Contingency stocks during the 20-year period are 485 million metric tons of food grains and 331 million metric tons of feed grains. Forty-two percent of the food grain stocks is used to meet shortfalls while 47 percent of the feed grain stocks is used, with associated storage costs of $9.20 per ton of food grain used and $8.10 per ton of feed grain used.

Food, feed, and all grain reserves for a 40-year period The worst weather expected in a 40-year period results in a decrease of 21.4 percent in all grain production, 26.7 percent decrease in feed grain production, and 18.2 percent decrease in food grain production. Consequently, the expected shortfalls, required contingency stocks, and the associated storage costs are all higher in a 40-year period than in the 10- and 20-year planning periods. Reserve levels equal to 19 percent of U.S. production of all grains or 43 percent of food grain production and 14 percent of feed grain production are required to meet the provisions of policy I. Forty-eight percent of the required stocks of 1,225 million metric tons of all grains are used to meet grain shortfalls. The contingency stocks of food grains is 748 million metric tons with 54 percent of the stocks used; those of feed grains are 649 million metric tons with 47 percent of the stocks used. Storage costs are $10.00 per ton of all grain used, $9.60 per ton of food grain used, and $9.90 per ton of feed grain used.

Grain reserves to meet 90 percent of U.S. domestic and 75 percent of foreign shortfalls: policy II

Policy II is designed to cover 75 percent of the foreign shortfalls rather than 60 percent as in policy I. Larger contingency stocks and associated higher storage costs thus are required. However, required stocks of food grains increase much more dramatically than do feed grains under policy II. The increase is larger since foreign countries are major producers of food grains. In addition, U.S. food grain production is small relative to U.S. feed grain production; thus, it takes a larger proportion of U.S. food grains than feed grains to meet a given world shortfall.

Food, feed, and all grain reserves for a 10-year period Table 13 indicates that reserves of 19 percent of U.S. grain production are sufficient to meet 90 percent of domestic grain shortfalls and 75 percent of the foreign shortfalls. The total contingency stock reserves for all grains during the period are 413 million metric tons, 35 percent larger than under policy I, 39 percent of the stocks are used to meet shortfalls during the period. Storage costs per ton used of $10.20 are $1.80 higher than under policy I.

Table 15 breaks the reserve requirements down into feed and food grain requirements. The food grain requirement under policy II is 312 million metric tons or 54 percent of U.S. food grain production, up 14 percent from policy I. Required feed grain stocks of 151 million metric tons or 11 percent of U.S. production are only 1 percent greater than under policy I. Storage costs rose accordingly to $9.90 per ton of food grain used and $7.50 per ton of feed grain used.

<u>Food, feed, and all grain reserves for 20-year period</u> Under policy II, required contingency stocks during a 20-year planning period are 861 million metric tons or 22 percent of U.S. grain production (Table 15), 36.6 percent of the reserves is used to meet shortfalls, with storage costs of $10.90 per ton used.

Required food grain reserves is 636 million metric tons, up 13 percent from policy I. Storage costs are $10.00 per ton of food grain used, $.80 higher than under policy I. There was no change in the required stocks or storage costs for feed grains between policies I and II for a 20-year period.

<u>Food, feed, and all grain reserves for a 40-year period</u> Twenty-four percent of U.S. production of all grains is required as reserves during a 40-year planning period under policy II. This amounts to 1,878 million metric tons, of which 34.7 percent is used to meet shortfalls. Storage costs under this alternative are $11.70 per ton used.

Table 15. **Estimated grain shortfalls, contingency** stocks reserved and used, and estimated storage costs of U.S. domestic grain reserves meeting policy II under conditions of worst weather expected in 10-, 20-, and 40-year periods

	All grains			Food grain			Feed grain		
	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.
Ratio of desirable U.S. domestic grain reserve to production trend (%)	19%	22%	24%	54%	55%	55%	11%	12%	14%
Grain shortfalls in million metric tons	192	383	754	162	323	628	87	173	353
Contingency stocks in million metric tons	413	861	1,878	312	636	1,271	151	331	772
Stocks used in million metric tons	161	315	652	124	251	483	75	154	306
Grain shortfalls uncovered in million metric tons	31	68	102	38	72	145	12	19	47
Ratio of the used stocks to total stocks	39.0	36.6	34.7	39.7	39.5	38.0	49.6	46.5	39.6
Storage costs per ton used in dollars	10.2	10.9	11.7	9.9	10.0	10.5	7.5	8.1	9.9

Again there is no change in the feed grain reserve requirements between policies I and II. Food grain requirements are higher, however. Required food grain reserves amount to 55 percent of U.S. production, 13 percent larger than policy I. Storage costs per ton of food grain used are also nearly a dollar higher.

Grain reserves to meet 90 percent of U.S. domestic and 60 percent of foreign shortfalls in insurance: policy III

Policy III differs from policy I in that it guarantees to cover 60 percent of foreign shortfalls every year, while policy I is designed to cover an average of 60 percent of foreign shortfalls over the planning period. Thus, a contingency stock large enough to cover 90 percent of U.S. shortfalls and 60 percent of foreign shortfalls in the same year is required.

Food, feed, and all grain reserves for a 10-year period Table 16 indicates that a reserve level of 8 percent of U.S. grain production covers 90 percent of U.S. domestic shortfalls under the assumption that the world experiences normal weather. Likewise, a reserve of 12 percent of U.S. production is sufficient to cover 60 percent of foreign shortfalls if the U.S. has normal weather (Table 17). Hence, a reserve level of 20 percent of U.S. production (6 percent higher than policy I) is needed to guarantee that both shortfalls could be covered in the same year.

Contingency stocks of 174 million metric tons are needed to meet 90 percent of the U.S. shortfalls, 32.8 percent of the stocks would actually be used to meet shortfalls. Storage costs are $12.60 per ton use (Table 16).

Table 16. All grains: estimated grain shortfalls, grain stocks reserved and used, and storage costs with alternative levels of U.S. domestic reserves under the assumption that the world experiences normal weather

	Ratio of U.S. Domestic Grain Stock Reserves To Production Trend (Percent)							
	6%	8%	10%	12%	14%	16%	18%	20%
	(million metric tons)							
Grain shortfalls	60	60	60	60	60	60	60	60
Contingency stocks	130	174	218	261	305	348	391	435
Stocks used	50	57	59	60	60	60	60	60
Grain shortfalls uncovered	10	3	1	0	0	0	0	0
Storage costs (million dollars)	517	715	923	1,135	1,248	1,454	1,667	1,988
Storage costs dollars per ton used	10.3	12.6	15.6	18.9	20.8	24.2	27.8	33.1

Table 17. All grains: estimated grain shortfalls, grain stocks reserved and used, and storage costs with alternative levels of U.S. domestic grain reserves under the assumption that the United States experiences normal weather

	Ratio of U.S. Domestic Grain Stock Reserves To Production Trend (Percent)							
	6%	8%	10%	12%	14%	16%	18%	20%
	(million metric tons)							
Grain shortfalls	141	141	141	141	141	141	141	141
Contingency stocks	130	173	216	259	324	367	389	432
Stocks used	54	67	70	90	103	112	116	124
Grain shortfalls uncovered	87	74	71	51	38	29	25	17
Storage costs (million dollars)	504	685	866	1,052	1,338	1,547	1,624	1,817
Storage costs dollars per ton used	9.3	10.2	12.4	11.7	13.0	13.8	14.0	14.6

Similarly, the contingency stocks of all grains reserved to meet 60 percent of the world's shortfalls are 259 million metric tons with 34.8 percent used to meet actual shortfalls. Storage costs are $11.70 per ton used. Thus, the total contingency stocks required (Table 18) are 433 million metric tons and storage costs to keep the reserve are $12.00 per ton used, $3.60 higher than under policy I.

The total food grain shortfall in the United States is 23 million metric tons over a 10-year period, while the world shortfall is 145 million metric tons (Table 18). Hence, the U.S. food grain requirement to meet U.S. shortfalls is much lower than that needed to meet world shortfalls. A food grain reserve of 8 percent of U.S. grain production trend covers 90 percent of the U.S. domestic shortfalls under the assumption than the world experiences normal weather, while one of 36 percent covers 60 percent of world shortfalls under the assumption that the United States experiences normal weather. Hence, the total food grain requirement to cover 90 percent of the U.S. domestic shortfalls and 60 percent of the world shortfalls in insurance is 44 percent of food grain production trend, 3 percent higher than under policy I. The total storage costs to keep the food grain reserves are $9.60 per ton used.

The U.S. feed grain requirements needed to meet U.S. shortfalls is approximately the same as required to meet world shortfalls. A U.S. feed grain reserve level of 8 percent of U.S. feed grain production trend covers 90 percent of U.S. shortfalls, and a reserve level of 6 percent of U.S. feed grain production trend covers 60 percent of foreign feed grain shortfalls. Hence, the total feed grain requirement to cover 90 percent

Table 18. Estimated grain shortfalls, grain stocks reserved and used, and storage costs of U.S. domestic grain reserves meeting policy III under conditions of the worst weather in 10-, 20-, and 40-year periods

	All grain			Food grain			Feed grain		
	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.	10 yrs.	20 yrs.	40 yrs.
Ratio of U.S. domestic grain reserves to production trend (%)	20%[a]	24%[b]	30%[c]	44%[d]	46%[e]		14%[f]	20%[g]	
Grain shortfalls in million metric tons	201	402	792	168	333		101	179	
Contingency stocks in million metric tons	433	935	2,079	255	532		194	551	
Stocks used in million metric tons	147	285	519	104	212		75	170	
Grain shortfalls uncovered in million metric tons	54	117	273	64	121		26	9	
Percent of the stocks used to total stocks	33.9	30.5	25.0	40.8	39.8		39.7	30.8	
Storage costs per ton used in dollars	12.0	13.7	17.2	9.6	9.8		10.2	13.5	

[a]Eight percent of U.S. production trend for U.S. domestic shortfalls and 12 percent for foreign shortfalls.

[b]Twelve percent of U.S. production trend for U.S. domestic shortfalls and 12 percent for foreign shortfalls.

[c]Eighteen percent of U.S. production trend for U.S. domestic shortfalls and 12 percent for foreign shortfalls.

[d]Eight percent of U.S. production trend for U.S. domestic shortfalls and 36 percent for foreign shortfalls.

[e]Ten percent of U.S. production trend for U.S. domestic shortfalls and 36 percent for foreign shortfalls.

[f]Eight percent of U.S. production trend for U.S. domestic shortfalls and 6 percent for foreign shortfalls.

[g]Twelve percent of U.S. production trend for U.S. domestic shortfalls and 8 percent for foreign shortfalls.

of domestic shortfalls and 60 percent of foreign shortfalls in the same year is 14 percent of U.S. feed grain production trend, 2 percent higher than under policy I. Storage costs over the period are $10.20 per ton used.

Food, feed, and all grain reserves for a 20-year period A grain reserve equal to 24 percent of U.S. production trend is required in a 20-year planning period; 21 percent to cover U.S. shortfalls and 12 percent to cover foreign shortfalls. This amounts to 935 million metric tons, 30 percent of which is actually used to meet shortfalls. Storage costs are $13.70 per ton used, $1.70 higher than in a 10-year planning period.

Food grain requirements are again greater than feed grain requirements. Food grain reserves require 46 percent of U.S. food grain production, feed grain reserves only 20 percent of U.S. feed grain production. However, storage costs per ton used are higher for feed grains than food grains since a smaller percentage of the feed grain reserves are actually used than are food grain reserves. Storage costs are $13.50 per ton for feed grains and $9.80 for food grains (Table 18).

Summary

As expected a greater coverage of shortfalls is associated with higher reserve levels and higher per unit used storage costs (Figure 3). Larger stocks must be maintained or added to during years of surplus and years with relatively small variations are more likely to occur than ones with severe deviations from trend, given that the deviations historically have been normally distributed (Figure 7). As a result, stocks tend to be stored longer and the average level of stocks on hand is larger. Both of these effects increase total storage costs. The lower relative frequency of the more severe deviations indicates that the majority of time the additional stocks will not be needed, resulting in a decline in the percentage of the stocks actually used to meet shortfalls. The combined effect of the increase in total storage costs and the smaller percentage of stocks used is a substantial increase in storage costs per unit used.

Other factors that affect the required level of reserves and the corresponding storage costs are the degree of supply variability the reserve policy is designed to alleviate and governmental policies that change the expected variation in grain production. Larger maximum deficits are expected during a 40-year planning period than during a 10-year planning period as Table 3 indicates. If the policy is designed to meet a fixed proportion of any given deficit, then larger contingency stocks would be be required under the longer planning period. Results from section VI indicate that the more "severe" the environmental policy imposed or the greater the level of production called for, the greater is the expected variability in production in any given year. This general increase in expected variability in turn increases the maximum shortfall expected in any given time period.

VIII. SUMMARY

U.S. agriculture shifted dramatically in the early 1970's from a situation with surplus stocks and price supports to essentially a free market with little reserves and no effective price regulations. Before

1972, U.S. agricultural prices had been supported above world levels and protective import tariffs had effectively insulated U.S. agriculture from the majority of foreign agricultural developments. A series of events in the early 1970's changed this insulation. A major factor was the large increase in export demand by the USSR. This increase was the result of crop failures in the USSR and the subsequent change in USSR import policy to replace the shortage rather than "tighten their belts" as was done in 1965. A second factor was the 20-30 percent increase in the value of foreign currencies relative to the dollar as a result of devaluations of the U.S. dollar. A third factor was reduced crops in competing export nations, especially Australia. The net effect was a substantial increase in foreign demand as countries replaced shortages or found that they could afford increased purchases of U.S. grains.

The large increase in export demand raised world prices above U.S. target prices and liquidated existing U.S. stocks of grain. In the absence of buffer stocks and with the equalization of U.S. and world prices, U.S. agriculture has become more closely integrated into the world agricultural system and as such, is much more susceptible to foreign supply and demand developments.

Given the general price inelasticity of demand for agricultural products and the relatively fixed supply of a commodity within a crop year, supply and demand variations are multiplied into relatively larger proportional changes in prices. As prices have reacted to the more volatile shifts in supply and demand, considerable uncertainty, distrust, and discontent has been generated among both producers and consumers who are unaccustomed to the volatile fluctuations in prices. Producers faced with this greater uncertainty react by discounting expected returns as insurance against price declines bringing about an economically inefficient underallocation of resources.

A grain reserve policy is one technique that can be used to offset the effects of demand and supply fluctuations. Among the possible objectives of a storage policy are to stabilize supply by changing the time distribution of supply, to stabilize prices, and to stabilize incomes. A storage policy is most effective in changing the supply available at any point in time. Since price fluctuations are a function of both supply and demand conditions and income a function of costs as well as output supply-demand conditions, changing the temporal supply distribution alone has less impact on stabilizing prices and incomes.

A major policy question is whether a storage policy should be designed as a domestic or international program. A domestic program exerts no control over the foreign demand component of price variability and thus, export controls could be necessary to prevent liquidation of domestic stocks. An international reserve internalizes the import-export problem. Other problems associated with a reserve program include the objectives of the program, the optimal size of reserves, the rules of accumulation and disbursement, location of storage, political control, and financing. In general, these problems will be much more difficult to resolve in an international than in a national framework.

The optimal size of a storage program will depend on the objectives of the program. Determination of the maximum shortage to be covered depends upon both the percentage of a given shortfall that will be covered and the maximum shortfall expected in the planning period. The results of section VII indicate that storage and handling costs per ton used are positively correlated with the percentage of a shortfall covered. In addition, the maximum expected shortfall is larger, although the probability it occurs in any given year is smaller, the longer the time period considered. With a reserve policy based on a 40-year planning period rather than a 10-year planning period a larger maximum deviation would be expected and correspondingly higher storage costs incurred.

The results in section VI indicate that grain production variability is positively correlated with the severity of the environmental policy imposed. As the policies become more restrictive as reflected by regional shifts in crop production, the weather-induced variability increases. This result should be qualified in recognizing that policies, such as our soil-tolerance level of allowable per acre soil loss, which help maintain the productive capacity of our soil resources may in the longer run reduce the weather-related variability. If we allow soils in the more productive areas to be eroded so that future production must be shifted into marginal, less productive areas the expected future variability in production could be much greater.

The increased production variability resulting from the implementation of an environmental policy in agriculture would, if combined with a grain reserve policy, increase the level of reserves needed to offset the greater supply fluctuations. The two general policies have conflicting impacts. The reserve policy is designed specifically to reduce the effects of weather variation on supplies, whereas the environmental policies tend to increase the weather-induced supply variation.

A second conclusion is that the implementation of an environmental policy merely reinforces the need for a storage program. In either case, trade-offs and interactions exist between the two policies and personal preferences regarding the relative merits of the policies will differ. Evaluation should be based on a joint analysis of the benefits and costs of the two policies. The analysis should be integrated into the framework of overall U.S. policy realizing that there are limited resources available for both problem solving and policy action.

Indications of substantially larger future populations and food needs suggest that the need for a reserve policy will be even more prevalent in the future. As production responds to the increasing demands, the level of production and the expected weather-induced variability in production will both increase as the results of section VI indicate. Deliberations concerning potential storage programs should account for these future possibilities as well.

REFERENCES

1. Allison, F.E. The Fate of Nitrogen Applied to Soils. Adv. Agron. 18: 219-258, 1966.

2. Arsdall, Roy N. Van, Richard B. Smith, and Thomas A. Stucker. Economic Impact of Controlling Surface Water Runoff from Point Sources in U.S. Hog Production. Agricultural Economic Report No. 263, E.R.S., U.S.D.A., July 1974.

3. Bailey, W.R., F.A. Kutish, and A.S. Rojko. Grain Stock Issues and Alternatives, a Progress Report. U.S. Department of Agriculture, Economic Research Service, Washington, D.C. 1974.

4. Buxton, Boyd M., and Stephen J. Ziegler, Economic Impact of Controlling Surface Water Runoff from U.S. Dairy Farms. Agricultural Economic Report No. 260, E.R.S., U.S.D.A., June 1974.

5. Federal Register, Vol. 39, No. 203, Friday, October 18, 1974. [FIFRA Docket Nos. 145, etc.].

6. Fuller, Wayne A. Grafted Polynomials as Approximate Functions. The Australian Journal of Agriculture Economics, Volume 13, No. 1, June 1969.

7. Johnston, J. Econometric Methods, 2nd edition. McGraw-Hill Book Company, New York. 1960.

8. Johnson, J.B., and G.A. Davis. The Economic Impacts of Imposing E.P.A. Effluent Guidelines on The U.S. Fed-beef Industry. Proceedings of the 1974 Cornell Agricultural Waste Management Conference-Processing and Management of Agricultural Wasters. Rochester, New York, March 25-27, 1974.

9. Meister, Anton D., and Kenneth J. Nicol. A Documentation of The National Water Assessment Model of Regional Agricultural Production, Land and Water Use, and Environmental Interaction. Center for Agricultural and Rural Development, Iowa State University, Ames, 1975.

10. National Academy of Sciences. Accumulation of Nitrate. Washington D.C., 1972.

11. National Economic Analysis Division. 1975 Fertilizer Situation. E.R.S., U.S.D.A., December 16, 1974.

12. Perrin, Richard K. and Earl O. Heady. Relative Contributions of Major Technological Factors and Moisture Stress to Increased Grain Yield in the Midwest, 1930-1971. CARD Report No. 55. Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa. 1975.

13. Schienbein, Allen. Cost of Storing and Handling Grain in Commercial Elevators, Projections for 1974-75. U.S. Department of Agriculture, Economic Research Service, Washington, D.C. 1974.

14. Shaw, Lawrence H. The Effect of Weather and Technology on Corn Yield in the Corn Belt, 1929-1962. Agricultural Economics Report No. 80, U.S. Department of Agriculture, Washington, D.C. 1965.

15. Snedecor, George W. and William G. Cochran. Statistical Method 6th edition. Iowa State University Press, Ames, Iowa. 1937.

16. Soil Conservation Service, Engineering Division. Procedure For Computing Sheet and Rill erosion on Project Areas. U.S. Department of Agricultural Soil Conservation Service Technical Release. No. 51. Sept. 1972.

17. Stall, John B. Effects of Sediment on Water Quality. Journal of Environmental Quality, Vol. 1, No. 4, 1972.

18. Statistical Reporting Service. Crop Production, 1975 Annual Summary: acreage, yield, production, by states. U.S. Dept. of Agricultural Statistical Report Service. CrPr-2-1 (76). January 15, 1976.

19. Thompson, Louis M. Weather and Technology in the Production of Corn in the U.S. Corn Belt. Agronomy Journal 61, pp. 453-456.

20. ________. Weather and Technology in the Production of Soybeans in the Central United States. Agronomy Journal, pp. 232-236.

21. U.S. Department of Agriculture. Agricultural Statistics. Economic Research Service, Washington, D.C. 1932-1972.

22. ________. Fluctuations in Crops and Weather, 1866-1948. Statistical Bulletin No. 101. U.S. Department of Agriculture, Washington, D.C. 1951.

23. ________. Grain Stocks in all Positions. Statistical Reporting Service, Crop Reporting Board, Statistical Reporting Service, U.S. Department of Agriculture, Washington, D.C. 1960-1972.

24. __________. The World Food Situation and Prospects to 1985. Economic Research Service, Foreign Agricultural Economic Report No. 98. 1974.

25. U.S. Water Resources Council. 1972 OBERS projections, Vols. 1-7. U.S. Government Printing Office. Washington D.C. April 1974.

26. U.S. Water Resources Council. 1972 OBERS projections supplement. U.S. Government Printing Office. Washington D.C. May 1975.

27. Vocke, Gary. "Study on the Restriction of Environmental Factors in the U.S. Grain Production." Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa. (forthcoming).

28. Wischmeier, Walter H., and Dwight D. Smith. Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains. Agricultural Handbook No. 282. Washington D.C. May 1965.

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